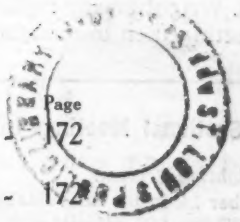
TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909 INCORPORATED 1930



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32 VICTORIA STREET
LONDON SW1

NOTES ON RECENT MEETINGS AND EVENTS

General Meeting in London.

A meeting of the Society was held in the Lecture Theatre of the Institution of Mechanical Engineers, Westminster, S.W.1, on Tuesday, December 13. The chair was taken by Dr. S. English at 7 p.m.

The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way. (See p. 206.)

The Chairman then called upon Dr. W. D. Wright to deliver his paper on " The Response of the Eye to Light in Relation to the Measurement of Subjective Brightness and Contrast," which was illustrated by numerous striking experiments. After a vote of thanks had been accorded to Dr. Wright, on the motion of the President, for his interesting paper, a discussion ensued in which Dr. R. J. Lythgoe, Dr. J. W. T. Walsh, Mr. A. W. Beuttell, Wing-Commander P. C. Livingston, Surgeon-Commander M. B. McLeod, Dr. W. S. Stiles, Mr. R. G. Hopkinson, Mr. E. W. Murray, Mr. J. S. Dow, and Dr. K. J. W. Craik took part.

Dr. W. D. Wright briefly replied to the discussion, and the meeting then terminated.

Sectional Meetings in London.

Industrial Lighting Section.

On November 14, in the unavoidable absence of Mr. C. A. Hughes, a discussion on Electric Discharge Lamps and their Application to Industrial Lighting was opened by Mr. C. R. Bicknell and led to a keen discussion. The meeting took place in the lecture theatre of the Junior Institution of Engineers. Mr. R. O. Ackerley presided.

Commercial Lighting Section.

At a meeting held at the E.L.M.A. Lighting Service Bureau on November 16, Mr. W. R. Stevens opened a discussion on Combined Tungsten and Electric Discharge Lighting of Commercial Premises, illustrating his remarks by numerous experiments. Mr. B. F. W. Besemer presided.

Decorative Lighting Section.

The meeting held at Gas Industry House on November 22 was devoted to a series of interesting problems, including Illuminated Fountains (Mr. A. Mansell), Cornices and Brightnesses; Laylights (Mr. A. W. Beuttell), and Unframed Glassware (Mr. G. Lovell).

Photometry Section.

Mr. J. M. Waldram presided over a meeting held in the lecture theatre of the Junior Institution of Engineers on November 29, when a discussion on " Outdoor Photometry " was opened by Mr. J. S. Dow. Apparatus was exhibited and described by Mr. G. H. Wilson, Mr. R. Maxted, and Mr. S. S. Beggs, and an interesting discussion ensued.

Public Lighting Section.

On December 9 a visit by motor-coach to various recent lighting installation in the London Area, including those in Hackney, Hornsey, and Paddington was arranged. About sixty members took part.

Meetings of Local Centres.

North-Western Area.

The three papers previously read in London on November 8 by Mr. J. M. Waldram, Mr. C. Dunbar, and Mr. F. C. Smith devoted to the Revealing Power of Street Lighting, were again presented at a meeting held in Manchester on November 16.

North-Midland Area.

The above papers were also presented in Leeds on December 12. A feature was the presence of representatives of quite a number of local authorities interested in street lighting.

This Section also held its first annual dinner and dance, over which the chairman, Councillor Sellers, presided, in Leeds, on November 18. Mr. W. J. Jones (vice-president) and Mr. J. S. Dow (hon. secretary) attended from London. The Section was congratulated on attaining official recognition, and the dinner, at which ladies were present, proved to be a very successful one.

Midland Area.

At a meeting held in Birmingham on December 2, Dr. W. M. Hampton gave an address on Glass Manufacture, in the course of which several descriptive films were shown. Dr. Howard Long presided.

Scotland.

The meeting on November 15 was devoted to an Exhibition of Photometric and Lighting Equipment, and was a very successful one. About fifty exhibitors took part, and there were approximately fifty objects of interest on view, both gas and electric lighting being well represented.

Irish Free State.

Two successful meetings have recently been held, on October 18, when Dr. H. H. Poole lectured on the Physics of Light, and on November 15, when a paper on Photometry was presented by Mr. H. B. Ruff.

SYNOPSIS OF MEETINGS

N.B. *Unless otherwise announced all meetings commence at 7 p.m.*

LONDON.

Dec. 19th. Light in Relation to Production (T. E. Catten); *E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, W.C.2.*

Jan. 10th. The Lighting of Cinema Auditoriums (E. Stroud and H. E. Weston); *Film House, Wardour Street, W.1.*

Jan. 17th. Discussion on Report of Departmental Committee on Factory Lighting; *Institution of Mech. Engrs., Storey's Gate, Westminster, S.W.1.*

Jan. 24th. The Relation Between the Illuminating Engineer and the Fittings Designer (H. Bright); *E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, W.C.2.*

Jan. 27th. The Design of Street Lanterns (J. Bertram and R. Maxted); *Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2.*

Jan. 31st. Visit to Dufay Chromex Laboratories, *Elstree.*

MANCHESTER.

Jan. 18th. The Lighting Requirements of a Large Store (O. Waygood); *Engineers' Club, Albert Square.* **(7.15 p.m.)**

LEEDS.

Jan. 9th. Decorative Materials and Their Response to Light (R. O. Ackerley); *The Electricity Showrooms, The Headrow.*

GLASGOW.

Dec. 21st. Some Aspects of Gas Lighting; *" The Gordons," 19, Gordon Street.* **(7.30 p.m.)**

Jan. 18th. Photometers and Photometry (H. E. de Weerdt); *19, Gordon Street.* **(7.30 p.m.)**

DUBLIN.

Dec. 20th. Problems Night; *Engineers' Hall, 35, Dawson Street.* **(6.30 p.m.)**

Jan. 17th. Electric Filament Lamps (E. D. McAlister); *Engineers' Hall, 35, Dawson Street.* **(6.30 p.m.)**

THE REVEALING POWER OF STREET LIGHTING INSTALLATIONS

By J. M. WALDRAM, B.Sc., F.Inst.P. *(Member)*

(Communication from the Research Laboratories of the General Electric Company, Ltd., Wembley, England.)

(Paper read on Tuesday, November 8th, 1938.)

NOTE.—The work which forms the subject of this paper was part of that contributed by the author to an investigation by the Experimental Panel of the Ministry of Transport Departmental Committee on Street Lighting into the measurement of visibility. This work was commenced in October, 1935, and reported to the Committee in June, 1936, but it has not been possible to publish it before. It represents only the work personally contributed by the author, and is without official significance. The paper should be read in conjunction with papers by Mr. C. Dunbar and Mr. F. C. Smith, describing their respective contributions to the problem.

SUMMARY.

The revealing power of a street lighting installation is distinguished from the "visibility" as generally understood. The factors which contribute to revealing power are examined, and a method is described for evaluating it. The method is compared with others that have been proposed, and its advantages and disadvantages are set out. Certain conclusions are given by way of example of the use of the principles given in the paper.

Introduction.

The measurement of visibility has always been one of the major problems of street lighting, and the interest in it has greatly increased during the last few years. The measurement of illumination, upon which so much reliance has in the past been placed, has been shown to be unreliable and often a misleading guide to the effectiveness of the lighting; measurements of brightness are more reliable, but are unstable and obviously incomplete. There is urgent need for a reliable yardstick with which "visibility" could be measured; and the work to be described is a contribution to a part of the problem of finding such a yardstick.

1. Definitions.

VISIBILITY, REVEALING POWER, AND APPEARANCE.

The problem of measuring visibility is partly solved by defining terms. The word is used in many different senses, some precise, some vague; and before any measurement or analysis connected with visibility can be usefully made, it must itself be defined, otherwise the results will be foredoomed to the criticism of not measuring visibility as the critic understands it.

In street lighting the word is so loosely used, and impressions of visibility are so influenced by factors which cannot be closely defined or measured, that no method yet suggested has really attempted to measure "visibility" in its popular sense. The property measured, though sometimes named visibility, has been the capacity of the installation to reveal objects (1). Similarly, no such attempt is made in this paper to measure "visibility," but it has been directed to a method of arriving at what has been called the "revealing power" of street lighting installations. This is not the same as visibility as commonly understood, as will be shown.

The quality of a lighted street described as the "visibility" seems to depend mainly upon its appearance. It is significant that almost all observers, whether qualified or not, are satisfied to inspect a lighted street when empty, and to express an opinion upon the "visibility." Any objects present are generally regarded as confirmatory rather than as essential evidence. There seems, indeed, to be some importance in the appearance of the empty road, for drivers and others are not satisfied with the lighting until it leaves them confident that they can see that the road is empty. The "appearance" of the road is the promise which it gives of its powers of revealing any objects which may be present, and the track ahead of the driver. In most installations the promise is fulfilled, but occasionally the appearance of the lighted street gives a false impression of its real capacity to reveal objects. Some instances will be given later. Serious discrepancies are not common; nevertheless, it is important to distinguish the *appearance* of the street, by which "visibility" is mainly judged, and its real *revealing power*, with which this paper is concerned. A more formal definition of "revealing power" is given later.

The distinction is not new; Preston Millar, who was responsible for much pioneer work on visibility, used much the same conception over twenty years ago (2). He referred to "revealing power" in a general sense, without defining or computing it, and to the "pleasing effect" of the installation, which apparently referred to the aesthetic effect rather than to the sense of safety. He carried out some very

(1) A possible exception may be found in a method due to A. J. Sweet (Trans. I.E.S. (Amer.), 1926, Vol. 21, No. 9, p. 982) of assigning arbitrary numbers to the various qualities of an installation and combining them to form a single figure of merit. It is not a measurement in an accepted sense.

(2) Preston Millar, Trans. I.E.S. (Amer.), 1916, Vol. 11, No. 4, p. 477. T. W. Rolph, Trans. I.E.S. (Amer.), 1925, Vol. 20, No. 1, p. 57.

elaborate tests having much the same aim as the present work, but used a technique unsuited to the present purposes. The form of the test and the absence of definition make it difficult to analyse or apply his results.

Visual Safety.

A further distinction should be made. Revealing power is obviously associated with safety, inasmuch as a high revealing power is sought in order to make a street as safe as possible. But revealing power is not visual safety. The former is concerned only with the extent to which objects are revealed to drivers; visual safety depends also upon the relative importance of various regions of the road. Thus, two installations may have the same revealing power, yet one may be safe and the other dangerous, because in one objects may be invisible in some unimportant region, while in the other they may be invisible in a very important region. Revealing power depends only upon the properties of the installation and of the observer, whereas visual safety would have to be derived from it by some system of weighting depending upon the requirements of various parts of the road.

2. Mechanism by which Objects are Revealed.

Objective and Subjective Factors.

Two groups of factors contribute to the revealing of an object: the things seen, and the capacity of the eye to see them. These groups have been named the objective and the subjective aspects of visibility (3).

The distinctions are not precise, but will serve for the present. The first includes such factors as the contrast which an object presents with its background; its absolute brightness, and that of its background; its size; its motion in the field of view relative to its background; and the like. The second group involves the adaptation of the observer's eyes, their previous history, glare effects, the amount of distraction to which he is subjected, etc.

The extent to which an object is visible to an observer is the result of a combination of the subjective and the objective factors. The present paper will not deal with the subjective factors, some of which are described by another investigator, (4) but in order to give some idea of the inter-relation of the many factors involved, the diagram shown in Fig. 1 has been prepared. This is intended to represent, along the bottom, some of the more important factors which affect the revealing power, and the way in which they, and derived factors, co-operate in revealing objects. For example, the brightness contrast is one of the most important of the objective factors; it depends upon the background brightness and the object brightnesses. Background brightness, in turn, depends upon road surface reflection properties; power, height, light distribution, spacing, and arrangement of light sources; haze; geometry of street; and position of observer. But the background brightness affects also the adaptation level of the observer's eyes, and the glare; and these two are themselves inter-related. The diagram will not be described in detail; but three general conclusions can be drawn from it: first, the inherent complexity of the problem; secondly, the limited control which the lighting engineer can exercise (the factors which he can control are those enclosed within a heavy line); and thirdly, the great importance, from many reasons, of the brightness of the background.

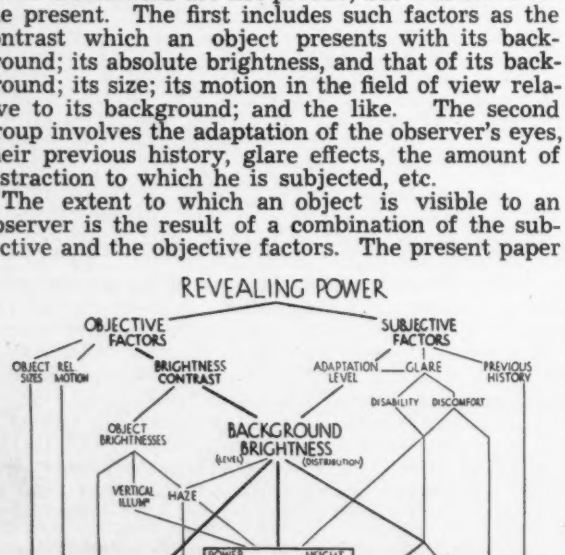

Fig. 1. Factors affecting Revealing Power.

Brightness Contrasts.

Objects are almost invariably revealed as a result of a difference between their brightness and that of their immediate background; difference of colour, as such, generally plays a minor part. Any large object may be seen against several parts of the background at once; but it follows from the geometry that most of the background to an object almost always lies a long distance behind it. Generally, the brightness of the object is different from that of the background, and it is necessary that a difference should exist if the object is to be seen. If the difference is small the observer's attention may not be drawn to the object; if it is very small the object may be invisible, particularly if the object and its background are both dark. It is not usually necessary for the whole of an object to present a large contrast with the background, but if a reasonably large part of it presents a good contrast, the presence of the object will be recognised. If only a small part can be clearly seen there is a chance that the nature or the distance of the object may be mistaken.

For a high revealing power, therefore, the lighting system must be so designed that a sufficient brightness contrast exists between the object, or a substantial part of it, and its immediate background, in all positions of the object and the observer and all reflection factors of object. The object is nearly always darker than the background, on account of the usual reflection properties of object and background surfaces; objects which are brighter than their background may occur, but it is rare for an object to be so much brighter than its background as to be clearly visible. (See Section 5.) In general,

(3) J. M. Waldram, Assoc. Publ. Ltg. Engrs. Conference, 1928.

(4) C. Dunbar, this issue of these "Transactions," p. 187.

therefore, high revealing power occurs when the object is dark and the background bright.

It follows that the revealing power will be greater where the background is brighter and less where it is darker. The revealing power of the installation is, therefore, not a unique figure, but a distribution, which is closely related to the distribution of brightness of the background.

Object Brightness.

The brightness difference between objects and their background obviously depends upon the brightness level and distribution of the background, and the brightnesses of the objects. (See Fig. 1.) The brightnesses of the objects will be dependent upon the illumination upon them and on their reflection factor. Imagine a large number of different objects occurring at random in the road. Their brightnesses will vary over a large range, and will have a statistical distribution([5]) depending upon (1) the distribution of illumination on the vertical faces of objects in the road, and (2) the statistical distribution of reflection factor. For example, unusually dark objects may occur because a very dark-coloured object is in a very dark place; and very bright objects may occasionally occur because an object of unusually high reflection factor happens to be particularly well illuminated. Most objects will have intermediate brightnesses; and a given object brightness may occur when a light object is poorly illuminated, or when a darker object is better illuminated; in fact, from an infinite number of combinations of illumination and reflection factor. Moreover, objects or parts of objects may occur anywhere within the significant parts of the field of view, so that the full range of object brightnesses may be seen against every part of the background.

The General Problem.

This, then, is broadly the state of affairs for which a yardstick is required. The observer is the driver of a vehicle. (The pedestrian observer is also important, but his requirements are less stringent.) His field of view, the angular size of which is very restricted, consists of the road surface, the footpaths, buildings, sky, light sources, and illuminated haze. These surfaces make up a complicated moving mosaic of different brightnesses, by which he has to recognise the track ahead; at the same time he has to make mental estimates of distance, curvature, and speed, solving unconsciously the complicated relationship between perspective and plan, and problems of relative velocity. Objects of different shapes and sizes, and having brightnesses which vary according to a complex statistical distribution, occur anywhere and appear to move against this complex background. The observer is subjected to peculiar visual conditions which are not constant, and has at the same time to control a vehicle in accordance with his interpretation of the background and of the objects upon it.

The problem is to find a measure of the degree to which the objects will be revealed to the observer. The capacity of the installation so to reveal objects, has been here called its revealing power ([6]). It is obviously inherently complex, and any successful method must take due account of its complexity. A simple "yardstick to measure visibility" is an obvious impossibility.

The principal characteristics of revealing power, which apply to all methods of measurement, can be summed up as follows:—

(1) The revealing power of a street lighting installation is not a unique figure, but a distribution.

(2) The distribution of revealing power is closely related to the distribution of background brightness, and although a given brightness level will not necessarily lead to the same revealing power in different installations, it will be shown that in any one installation lines of equal brightness are usually to a close approximation, also lines of equal revealing power.

(3) Revealing power generally cannot usefully be averaged to give a single figure. It may be possible, by weighting the revealing power in different regions of the field of view, to arrive at a figure for the visual safety of the installation; such a process would necessarily be empirical.

(4) Since the revealing power is intimately connected with the brightness distribution, it is likely to vary with such factors as the curvature, gradients, change of viewpoint, alterations in the positions of the sources, etc.

(5) Since rain, mist, variation of surface conditions, etc., will alter the background brightness, revealing power deduced from one set of measurements is representative of the installation only at the time of measurement.

3. Proposed Measure of Revealing Power.

Assumptions and Basis of Method.

In order to reduce the problem to manageable terms, consider a single viewpoint in the installation([7]). Consider also objects which are small (about 18-in. square) plane surfaces with their normals parallel to the axis of the road. An actual obstruction, such as a pedestrian or a car, might be considered as consisting of several of these objects. The viewpoint would normally be chosen to show some feature of the lighting which it was desired to investigate; this can be estimated beforehand, having in mind the purpose for which the results are required. Consider an observer, 5 ft. high in a typical position, for example, 10 ft. from the kerb and under

([5]) The "statistical distribution" is the relation between the object brightness (or reflection factor, as the case may be) and the percentage number of objects having that brightness (or reflection factor).

([6]) Later in the paper the term is used in a stricter sense.

([7]) As Dunbar shows, this does not correspond to a stationary observer, but approximates to considering an instantaneous view by a moving observer. It does not, however, completely take into account all the effects of motion. (See Section 5.)

one lantern. The basis of the method can be more easily followed if it is approached in two stages.

(i) *Single Object.*—Consider first one such small object. Since it may represent the upper part of a real obstruction, it may not be at the road surface, but raised above it; consequently it may be seen against any part of the background. The reflection factor is, of course, constant, and therefore the brightness of the object will vary in proportion to the illumination falling upon it, from that due to the maximum illumination on vertical planes in one span, to that due to the minimum illumination. If the object occupies all its possible positions, it will appear at all brightnesses over this range against every part of the background (except over the immediate foreground, which is less than one span distant, so that objects seen against it cannot receive the full range of illumination).

Suppose that the curve showing illumination on vertical surfaces along the street has been found. The

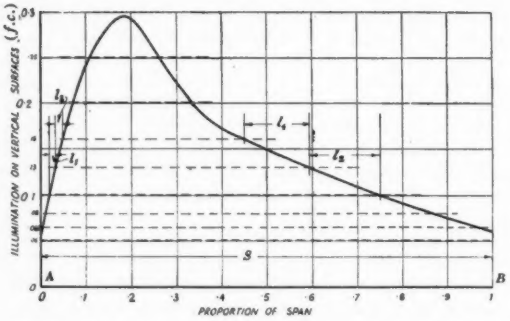

Fig. 3. Typical curve of illumination on vertical surfaces.

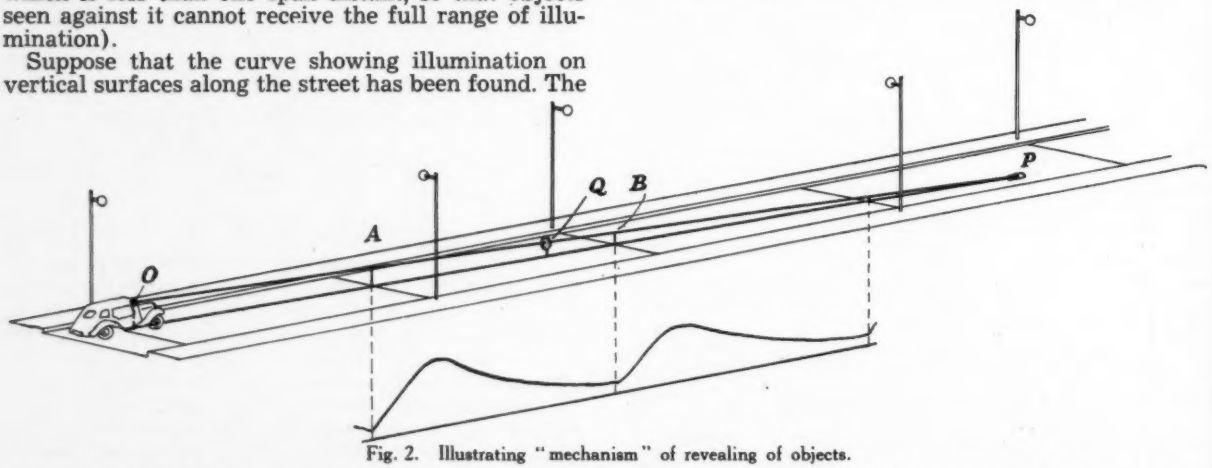

Fig. 2. Illustrating "mechanism" of revealing of objects.

object brightnesses, for a given constant reflection factor, will vary somewhat as indicated diagrammatically in Fig. 2, being a maximum on a line through the lantern making an angle of about 45 deg. to the vertical, i.e., when distant from the lantern by an amount equal to the mounting height, and a minimum when opposite to a lantern. In this figure, let O represent the observer, and P any point on the background. Any object Q which lies on the line of OP will, of course, be seen from O against P. If we consider the single object of fixed reflection factor, moving up and down OP, then it is possible to derive, from the curve of illumination on vertical surfaces, the probability that any given brightness will occur. In Fig. 3, which represents a typical curve of illumination on vertical surfaces, let the range of illumination be divided into zones, as shown. Then the proportion of the length of the span can be found, over which the illumination lies within any given zone; for example, in Fig. 3 the illumination lies between 0.1 and 0.13 ft.-candle for a proportion $(l_1 + l_2)/S$, and between 0.13 and 0.16 ft.-candle for a proportion $(l_3 + l_4)/S$, and so on. Since the object has an equal chance of appearing at any point in the span, these proportions represent its chance of appearing illuminated to the corresponding levels; and, since the reflection factor is constant, they represent its chances of appearing at corresponding brightnesses. This probability can be plotted as a curve, as in Fig. 4, preferably showing the percentage number of positions at which the object brightness is below

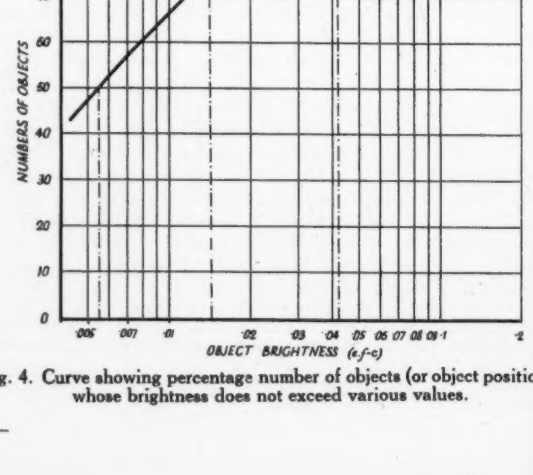

Fig. 4. Curve showing percentage number of objects (or object positions) whose brightness does not exceed various values.

various values. (The data of Fig. 4 refer actually to a later calculation, but the curve illustrates the principle. The logarithmic scale is used only for convenience.)

Suppose now that an experiment has been made to find the brightness differences between the object and the background, which are necessary if drivers are to be satisfied that they will notice the object, for various object brightnesses in the conditions of the installation([8]) (Fig. 5). Then for each value of object brightnesses, a corresponding background

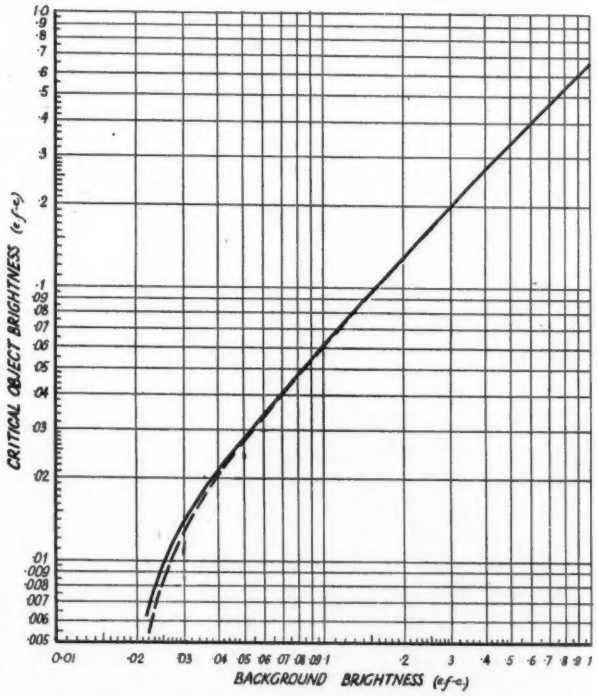

Fig. 5. Curve showing critical object brightness and background brightness. (From Dunbar. Full curve is standard curve; dotted curve shows standard curve corrected for glare for installation shown in Fig. 7.)

brightness can be found which is just sufficient to reveal objects of that brightness. For example, consider a small object of some given reflection factor, and suppose that it was found from the illumination curve that in moving from A to B (Figs. 3 and 4) its brightness was below 0.008 e.f-c. ([9]) for 60 per cent. of the span, below 0.02 e.f-c. for 80 per cent., and below 0.043 e.f.-c. for 95 per cent. of the span. These percentages will then be the probabilities that the brightness of the object will be below the corresponding levels. Now from Figure 5, in order to reveal an object having a brightness of 0.02 e.f-c., the brightness of the background must be 0.039 e.f-c.; so that at all points of the background, such as P, at which the brightness is 0.039 e.f-c., all objects of 0.02 e.f-c. or less will be visible, and therefore the object will be seen in 80 per cent. of its positions. It would then be possible to say, implying a more definite definition of revealing power, that at all points of the background having a brightness of 0.039 e.f-c., to which the above percentages apply, the revealing power was 80 per cent. for objects of the reflection factor considered. Similarly, it might be found that at all points of the background having a brightness of 0.075 e.f-c. the revealing power for objects of that reflection factor was 95 per cent., because that background brightness was just sufficient to reveal objects whose brightness did not exceed 0.043 e.f.-c. Proceeding in this way, we could produce a map of the revealing power, for objects of that reflection factor, if we have a map of the brightness distribution over the background.

The above argument makes certain assumptions. For example, it assumes that the curve of illumination on vertical surfaces is the same for different positions of P, although P may travel all over and across the road, so that OP may lie below a line of sources or may be in the middle of the road away from the lines of sources. In some installations this would not be justified, particularly when the carriage-way is wide, or where single-side mounting is used. Measurements made in the course of the work showed, however, that in normal installations the variation between the results from an illumination curve taken in the middle of the road and one taken at the edge is not serious, and in most cases it would be sufficiently accurate to take one typical curve. When it is suspected that this is not justified, two or more curves can be taken and each applied within the appropriate parts of the field of view. Again, it is assumed that the values obtained for the proportions of the span over which certain illumination values occur represent the chances of objects occurring having those illuminations. This is not necessarily true for the parts of the background less than one span distant. Such parts are in the immediate foreground and are generally not very important; if for some reason it is desired to investigate them, an adjustment can be made as necessary. It is also assumed that objects are darker than their background. The validity of this is discussed later.

(*ii*) *Extension to varying reflection factors.*—The above argument has been based upon a single object of fixed and known reflection factor. In practice, the reflection factor of objects varies considerably, from objects of 1 per cent. or less (pedestrians wearing dark winter clothes) to 30 per cent. or 50 per cent. (women's summer clothes, white flannels, light-coloured vehicles, etc.). This must obviously be taken into account if the results are to represent practical conditions. In practice, the reflection factor of the objects will vary according to a statistical distribution. Fig. 6, which is taken from Smith's paper ([10]),

([8]) C. Dunbar, loc. cit. The curve given in his paper has been replotted to show critical object brightness instead of critical brightness difference, for convenience in use.

([9]) 1e.f.c. = 1 equivalent foot-candle $= \frac{1}{\pi}$ candle per sq. ft.

([10]) F. C. Smith. This issue of these "Transactions," p. 200. This curve has been plotted for convenience on a logarithmic scale.

shows such a distribution of reflection factors taken for pedestrians' clothing. These objects will be scattered on the road and will be subjected to a varying illumination as described above. The chance of objects appearing at a given brightness level is now not simply derived from the illumination curve alone, but must be obtained from the interaction of the illumination and the reflection factor. A given brightness may, as explained earlier, occur as the result of many different combinations of reflection factor and illumination. But if the curve of illumination on vertical surfaces is known, and if the statistical distribution of reflection factor for the objects is also known, then the statistical distribution of object brightnesses can be calculated by a method given in Appendix I. The distribution can again be drawn in the form of a curve similar to Fig. 4, showing the percentage number of objects, the brightnesses of which lie below given values. From this curve the object brightnesses can be read off, below which various given percentages of the total number of possible objects lie; and the corresponding background brightness can be read from the curve of Fig. 5, which is taken from Dunbar's paper and shows the relation between the object brightness and the critical background brightness necessary just to reveal the object safely to the driver.

If the curves shown in Figs. 5 and 6 are available, it now becomes possible to plot, from data of the road

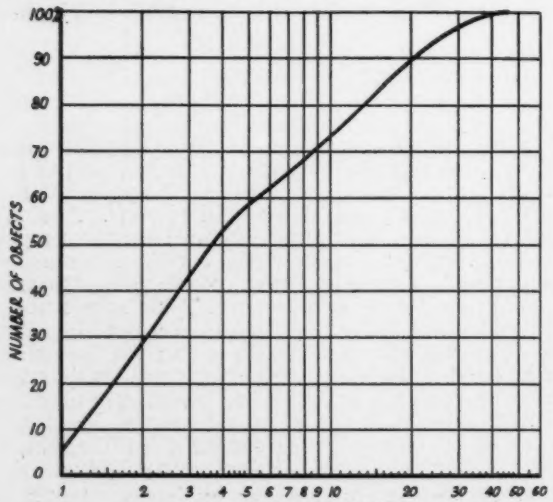

Fig. 6. Curve showing percentage number of objects the reflection factor of which does not exceed given values. (From Smith.)

obtained by ordinary photometry, the revealing power of the road for all objects and to define specifically the revealing power. It will be seen from the way in which it has been derived that:

> The revealing power of a given part of the background of a street lighting installation is the percentage of all possible small vertical plane objects facing the observer, having the same statistical distribution of reflection factor as pedestrians, and in all positions in which they are seen in line with that part of the background, which will present sufficient brightness contrast to be seen at least adequately for the purpose of a driver.

Necessary Field Work.

In order to obtain the revealing power distribution in an installation, therefore, two surveys are necessary: first, a survey of the distribution of brightness of the background, as seen from the selected viewpoint, and second, a survey of the illumination on vertical surfaces in the installation. The former is best carried out by the method of photographic photometry,[11] in which the field work consists mainly in the taking of a photograph from the selected viewpoint, which can subsequently be contoured with lines of equal brightness. It is also possible to make a sketch or photograph of the installation upon which readings can be marked, taken with a brightness meter or telephotometer, but this method is less satisfactory. In any case, when the brightness levels of the background corresponding to given values of revealing power are known, these values can be marked on a photograph or drawing of the road in perspective, so as to show the regions of the field of view at which the revealing power has the corresponding values. Figs. 7 and 8 show a photograph of an installation so contoured with two different

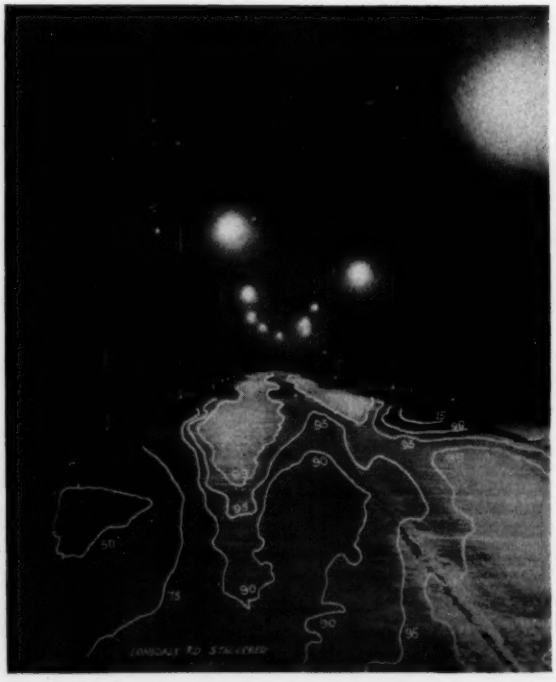

Fig. 7. Installation with staggered arrangement. Test Point illumination 0.08 ft.-candles.

[11] J. M. Waldram, Ill. Eng. (Lond.), 1934, p. 305; J. Sci. Instr., 1936, XIII. (11), p. 352. A. Bloch, J. Sci. Instr., 1936, XIII. (11), p. 358.

powers of sources, and Figs. 9 and 10 show another installation of similar powers, but with a different arrangement of sources.

TIME REQUIRED FOR FIELD WORK AND CALCULATION.

In practice the survey of vertical illumination can generally be confined to one line in one or two spans at a height of about 4 ft. It is a convenience in further calculation if readings are taken at intervals of 1/10 of the span, with an extra reading if necessary at the maximum, in order to define the curve. This can be carried out in about half an hour or less, excluding the time necessary to prepare instruments and to mark out the road. If the method of photographic photometry is used, or if a record photograph is taken, the taking of the photograph can proceed at the same time as the measurements of illumination,

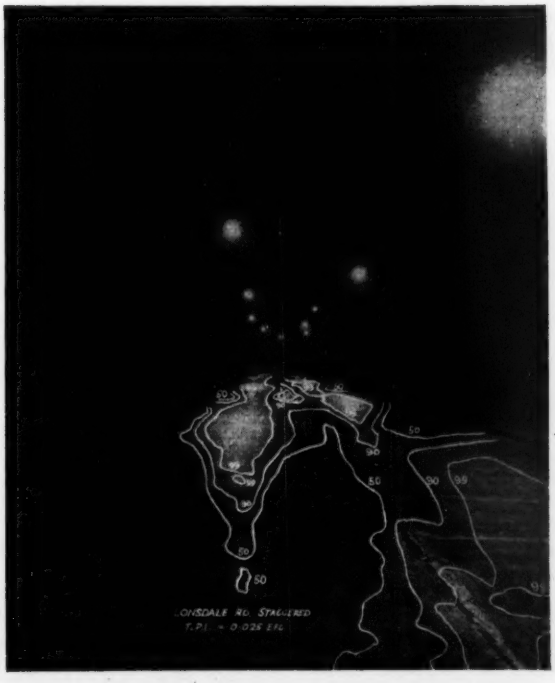

Fig. 8. Installation with staggered arrangement. Test Point illumination 0.025 ft.-candles.

if sufficient staff are available. The taking of the photometric photograph requires about twenty minutes, depending upon the traffic, including the time taken in setting up. A record photograph would generally be taken as well. Thus, in favourable circumstances, the field work in one installation would take about half an hour to three-quarters of an hour, which is short enough to enable several installations to be compared in a single night's work. The making of the comparison exposures on the plates, which is performed in the laboratory preferably immediately on returning, requires about three-quarters of an hour for a night's photographs. In favourable circumstances, and with proper organisation, revealing

Fig. 9. Installation with central arrangement. Test Point illumination 0.08 ft.-candles.

Fig. 10. Installation with central arrangement. Test Point illumination 0.025 ft.-candles.

power results could be obtained on two or three installations in one night's work for three or four observers and the final contours available a day and a half later, in normal working and allowing rest time for the observers who have been on night work. This is not unduly long for a method to be used in lighting research.

4. Purpose and Requirements of Measurements of Revealing Power.

The above method was devised having in mind the purposes for which measurements of revealing power are required, and certain conditions which any system of measurement must fulfil.

The first is that it should obviously be possible to analyse the results. Measurements of revealing power or visibility, however defined, would doubtless be required in the first place for research purposes, for changes in atmospheric and surface conditions produce sufficient day-to-day variations of revealing power, brightness distribution, and appearance in the same installation to make any such measurements of doubtful value as, say, an acceptance test or a criterion of maintenance. In the present state of knowledge, their main value would no doubt be to settle problems of light distribution, source height, position, and the like; and they would have to be used to compare one installation with another, if possible on the same road and on the same occasion. In view of the complex interrelation of the many factors concerned, it will obviously be important to be able to analyse the results of the measurement. Suppose, for example, that two light distributions are being compared, and that it is found that one gives a lower revealing power than the other. It will immediately be asked why this is so. For example, is the one worse because it produces greater object brightness or a poorer brightness distribution on the carriageway, or is the fault due to some accident of the roads in which the tests were made? What particular feature of the distribution is responsible for the poorer result, and how can it be improved? For this reason, even if an instrument could be devised which would indicate correctly the revealing power on a scale (assuming that it could usefully be expressed in a single figure), such a device might be of limited usefulness, because its results could not be analysed. There are so many fortuitous variables which might outweigh the effects studied that a "blind" indication of this kind would have to be accepted with great caution.

For similar reasons, any measure should not be empirical, but should have a defined meaning. Many forms of "visibility" tests have been proposed, using some artificial criterion such as the noticing of an arbitrary test object in arbitrary positions, and weighting the results in different ways, which are really attempts to measure revealing power; but the results are difficult to interpret generally because they are peculiar to the form of test [12]. Some investigations have been criticised because they measure a visual function, such as visual acuity, which is not germane to the problem. Simplifying assumptions will obviously be necessary in any method, but if the meaning of the measurements is rational and defined, it may be possible to make allowances for the assumptions in interpreting the results.

Another requirement of any system of measurement is that it should be as sensitive and reliable as possible. A measurement of revealing power is only valuable as an improvement on the opinions and observations of qualified observers; the assumptions which are made to simplify the problem must therefore not seriously impair the reliability of the method of measurement.

From these considerations it might be found that no satisfactory method of measurement could be devised at all, for no satisfactory compromise could be made between sufficient simplicity and sufficient accuracy. The method suggested in this paper is not very simple or rapid; it is probably most suitable for use in research problems of sufficient importance to justify a fairly elaborate investigation. It is, however, thought to fulfil the requirements set forth above sufficiently for its results to be useful.

5. Criticisms of Method and Interpretation of Results.

Comparison With Published Methods.

The method described differs from those adopted by earlier workers on visibility in several particulars. Most other investigators have sought to explore an installation by placing in it test objects of various forms at known positions, arbitrarily selected, and by judging in some way whether or not they could be seen [13]. The observation conditions vary considerably; in some experiments the observers walked, drove, or were driven along the road, while in others they were stationary and not in a vehicle. Sometimes they knew that they were taking part in an experiment and what they were expected to see; sometimes the observer did not know what to expect or even did not know that he was taking part in an experiment at all, for the test was arranged to be made by the casual users of the road without their knowledge.

The proposed method differs from these in that the field work consists only of photometric measurements made by established methods, from the results of which the revealing power is determined by calculation. The necessary visual data are obtained from experiments carried out once and for all by skilled observers driving under controlled conditions which approximate as closely as possible to the actual driving conditions in the installation [14]; the data of the reflecting properties of the objects which commonly occur in streets are obtained from measurements of the clothing of a large number of pedestrians [15].

This procedure has several advantages: (i) The results can be analysed and if necessary elaborated

[12] C. Dunbar, loc. cit.

[13] e.g., Preston Millar, loc. cit. Goodell, Trans. I.E.S. (Amer.), 1935, Vol. 30, No. 1, p. 49. English, Trans. I.E.S. (Lond.), 1937, Vol. II. (6), p. 68. (This work was published after the present work had been reported to the Departmental Committee, but without knowledge of it.)

[14] C. Dunbar, loc. cit.

[15] F. C. Smith, loc. cit.

after the field work is completed. (ii) They have a defined meaning, so that arguments can be based upon them. Empirical methods require some sort of calibration in terms of the opinions of observers, and must be used with caution in installations which differ from those by which they were calibrated. (iii) The difficult visual measurements necessary to establish the visual basis of the method have not to be repeated at every test, but are made once and for all under more accurate conditions. Moreover, even if some inaccuracy occurs in their determination, they are consistent from one experiment to another. (iv) It is possible to take into account an infinite number of objects, whereas methods using direct observation are confined to the objects observed.

Effect of "Reversed Silhouette."

The importance of "reversed silhouette," i.e., the revealing of objects as light objects on a darker ground, has not yet been discussed. As can be seen from Fig. 5, the critical brightness difference is for the higher levels about one-half the background brightness. Assuming—as seems reasonable—that the value of the critical brightness difference is unchanged by its sign, i.e., that it is the same if the object is lighter than the background, then if the brightness of an object is slowly raised from zero it will become inconspicuous when its brightness is half the background brightness, and will remain so until it is about 1½ times the background brightness, i.e., at about three times the brightness at which it disappears as a dark object, it will reappear as a light object. The additional revealing power due to objects revealed by reversed silhouette can be calculated by an obvious inversion of the calculation for direct silhouette.

Calculation of a typical case of a non-cut-off installation showed that additional revealing power for reversed silhouette would amount to 3.4 per cent. at 50 per cent. revealing power, 1.2 per cent. at 75 per cent., and at higher values negligible ([16]).

Validity of Results.

The validity of the contours of revealing power in a given installation depends mainly upon the curve which is used for the critical brightness difference, of which Fig. 5 is typical. Dunbar has explained the conditions under which the data have been obtained, and the manner in which the relation varies on account of glare and of the patchiness of the background. The curve may be corrected to the conditions of a given installation from the data which are given in his paper to any degree which the experiment may demand; for many purposes, however, the curve given in his paper will be quite sufficiently accurate, particularly when similar installations are being compared. The dotted curve of Fig. 5 shows the standard curve corrected for glare for the installation of Fig. 7. The necessity for such correction depends upon the degree to which the application of the correction will affect the final conclusions drawn from the experiment. For example, the application of a correction might change the brightness which represents a given revealing power by 15 per cent. In a normal brightness distribution, however, the position of the contour would be very little altered, and conclusions drawn from the distribution of revealing power over the whole field of view might be unchanged.

The results also depend upon the curve found for the statistical distribution of object brightnesses. This depends upon the illumination curve found, and upon the reflection factor distribution employed. The latter curve can be modified without affecting the theory or the validity of the method, for only the numerical result will be affected. Here it is mainly important to have an agreed standard curve, approximating to the real distribution, but not necessarily strictly accurate; the main consideration is that all results should be based upon the same curve. (The internationally agreed spectral luminosity curve, which is the basis of heterochromatic photometry, is an analogy.) For a discussion of this curve, the paper by Smith should be consulted. The degree to which a single illumination curve applies to the whole field of view depends again upon the circumstances of the case; it is always possible to take more than one curve and to apply each curve to an appropriate region.

The effect of mist introduces an error which is not compensated for in the procedure as described. The general effect of mist is to increase the brightness of the more distant objects and backgrounds, for the mist is illuminated and scatters light into the eye which would not otherwise enter it. In the method as described the effect of mist is taken into account so far as it affects the backgrounds, but not in so far as it affects the objects; and if it is not corrected for the revealing power found it will be too high, particularly in the more distant parts of the field of view. This is a disadvantage of the method as compared with methods in which actual objects are observed on the street, and must be set against the various advantages mentioned above. It can be minimised by making tests on clear nights, which would be the normal procedure for most experiments, and it can be compensated for by making measurements of the brightness of black screens placed at known distances, say, at each post on one side of the road, and by applying the results to the object brightness curve.

5. Interpretation of Results.

The expression in numbers of any quantity or property must always be made in three stages: the statement of the problem and exact definition of the quantity to be measured; the devising of a system of measurement and a scale upon which the measurement can be made; and the interpretation of the numbers when the measurement has been made. The three are of equal importance, and measurements are not valuable until all three have been completed.

The numbers resulting from a measurement are not valuable unless it is known exactly what they

([16]) Chanon and Reid's experiments on a model highway lead to similar conclusions. (Trans. I.E.S. (Amer.), 1936, Vol. 31, No. 5, p. 481.)

represent, and unless they have been correlated with experience of the property measured. It is, for example, useless to take one's temperature unless the normal body temperature is known, and unless some experience exists to enable variations from the normal to the interpreted. In most measurements such experience exists and is taken for granted, but in new forms of measurement the experience must be acquired. In the present instance there has not yet been sufficient experience to decide numerical limits for, say, just adequate revealing power, or to interpret fully the meaning of departures from usual distributions. For this reason the method of measurement has been stopped at the point at which the meaning of its results is definable, and involves the minimum of assumptions, for the present experience does not justify taking the figures further. The way in which revealing power distributions are interpreted will depend upon circumstances; in some instances the interpretation will be obvious, in others it may be less so, and will be a matter for judgment. This is inherent in the problem; it is not the fault of this method, but applies to all methods.

Some of the problems of interpretation can be discussed.

Visual Safety.

It has already been pointed out that revealing power is not the same as visual safety, inasmuch as it does not distinguish between parts of the carriageway of different importance to the driver. In order to obtain any figure for visual safety, some empirical weighting would have to be applied, the basis for which is not very easy to define. It has not been attempted in the present paper.

Meaning of Low Revealing Power

A revealing power of, say, 80 per cent. does not imply that there are twenty chances in a hundred of a collision occurring, for several reasons. In the first place, it is based upon small objects, and practical large objects must be considered as consisting of several small objects. A pedestrian, for example, might be taken as consisting of four such small objects, not all of which have the same probability of brightness. Moreover, whereas a single small object might lie in a region of uniform revealing power, a larger object is much more likely to cover regions of different revealing power, so that in both counts its chance of being revealed is higher than the chance of a single small object. The objects considered have been flat, and solid objects are often revealed by shadows upon them which do not occur with flat objects. Again, the revealing power has, in any case, been investigated for a single viewpoint in the path of a driver; but in practice, since the driver, and often the object as well, will be moving, the chance of the object remaining in a region of low revealing power as the vehicle approaches may be reduced considerably to a degree which varies with the local circumstances. If the object appears to move relatively to the background, it will, in any case, be more noticeable; the effect of relative motion has only partly been included in the present method. Finally, the statement that the revealing power in some small region is 80 per cent. implies only that 80 per cent. of the objects *seen against that region* will be visible. But it may be that of all the objects present in the street, only 5 per cent. would be seen against that region, so that only 1 per cent. of the objects present would be rendered invisible, owing to that particular region. These facts do not invalidate the calculation of revealing power; but they imply that results need careful interpretation, and indicate the ways in which the interpretation should be performed.

Overall Revealing Power.

It is possible, by a method given in Appendix II., to calculate the overall revealing power, which is the percentage which would be revealed of all small objects of the type considered, scattered uniformly over the carriageway.

Such a figure needs to be accepted with caution, and interpreted in the light of the distribution of revealing power as indicated by the contours. The revealing power is intended to be used as one aid in assessing the relative merits of various distributions and systems of street lighting; and other factors must be considered in addition, such as the location of regions of low revealing power and the general appearance of the lighted street. For example, Figs. 7 and 9 show two installations of similar powers, one with staggered arrangement and one with central. The overall revealing power in the two cases is 98 per cent. and 96 per cent. But these two figures do not represent the relative merits of the two arrangements, even restricting the argument to the simple question of revealing objects only and omitting questions of appearance. The centrally mounted system has only slightly lower overall revealing power and, in the opinion of some, the more smooth and pleasing appearance; nevertheless, experience with the two demonstrated that it was the less satisfactory in practice because, among other things, the revealing power was low at the sides of the road, and because objects near the kerb could remain in an area of low revealing power until they were approached.

6. Some Conclusions.

It is not intended to give the results of the application of the method to specific problems. From a study of the calculation, however, and of the shape of certain of the curves, certain principles emerge; and some other general conclusions are given by way of example of the deductions which can be drawn from the nature of revealing power and a knowledge of the factors which affect it. They are not intended as exhausting the questions which are discussed, but only as examples of the use of the principle of revealing power.

A general conclusion from the study of revealing power is that the dark regions of the road are the sensitive regions, where objects may disappear, where disability glare can have an effect, and where reverse silhouette can occur. Any factor which acts adversely upon the revealing of objects generally has most

effects in the regions of low brightness, and these regions are for several reasons the weak spots in the installation.

Since revealing power derives from the separate factors of the brightness of the objects and that of the background, it is obvious that to obtain a high revealing power, a light distribution and a source arrangement must be used which operate both these factors in the right direction. It is not useful, for example, to seek to increase the background brightness, by methods which at the same time so increase the object brightness that the revealing power is unchanged. The tendency of certain variables to affect revealing power can be ascertained by considering their effect upon these two factors.

Effect of Power of Installation on Revealing Power.

Dunbar has shown from the shape of the curve of critical contrast that the revealing power increases as the power of the installation increases where the level of brightness is low. When the brightness of any part of the background reaches about 0.1 e.f-c., however, the increase with increasing power at that part becomes very slow, and at points above about 1.0 e.f-c. the revealing power is independent of the power of the installation. For the reasons for this, his paper should be consulted. It is interesting, both as an example of the difference between appearance and revealing power—for the appearance seems tc benefit by increased power after the revealing power has ceased to do so—and also from the conclusion that when the power of an installation is reduced, the regions of low brightness are the first to suffer. An example of the effect of altering the power of the installation is shown in Figs. 7 and 8, or 9 and 10.

An Effect of Light Distribution on Revealing Power.

A change of light distribution can alter the balance between the object brightness and the background brightness, and, therefore, the revealing power. For example, a non-cut-off distribution tends to produce a higher background brightness than a cut-off distribution of the same power and quality, because the bright areas associated with each light source are brighter and tend to overlap, whereas the cut-off distribution reduces both the brightness of the areas and their size, so that they overlap little. On the other hand, the illumination on objects is relatively higher with a cut-off system; for the maximum object illumination occurs at about 45°, at which angle the type of distribution is immaterial, and the short spacing associated with a cut-off distribution tends to keep the object illumination higher. Consequently, the revealing power tends to be lower in the cut-off installation, to an extent not compensated for by the reduction of glare. In some good cut-off installations the revealing power may nowhere reach 99 per cent., whereas in good non-cut-off installations it is usual to find large areas of 99 per cent. Observations of light-coloured objects, e.g., pedestrians, in both types, confirm this conclusion, for in some cut-off installations such objects can sometimes disappear completely and unexpectedly in a disconcerting way. This does not necessarily imply a serious disability of the cut-off system, however, for, as shown above, the revealing power can drop below 100 per cent. without implying that the lighting is necessarily dangerous; and this type of lighting, properly carried out, has a very attractive appearance owing to the shielding of the glare sources. This is yet another instance of the difference between appearance and revealing power. In well-designed cut-off installations, the revealing power is generally adequate for the purposes of drivers; in others, it is not so good as it appears to be.

Effect of Height of Sources on Revealing Power.

Alteration of the mounting height of the sources affects both the illumination of objects and the brightness distribution upon the road. The illumination of vertical surfaces rises to a higher maximum as the height is reduced; the minimum may increase or decrease or be little changed according to the type of light distribution used. The overall effect is that the distribution curve of object brightnesses is shifted to the right, indicating an increase in the brightness corresponding to a given percentage of the objects. The effect on the road surface brightness is to produce a more patchy effect; the dark parts are rendered darker and the bright parts brighter as the height is reduced.([17]) Since an alteration in the brightness of the background has most effect in the darker regions, the net effect is to reduce the revealing power on this count also. In addition, the reduction of height is accompanied by an increase in glare. On all three counts, therefore, the revealing power is reduced as the height is reduced. The amount of the reduction is, however, not necessarily very great; and in an installation in which the revealing power is satisfactory when the mounting height is 25 ft., a reduction of height to, say, 18 ft. may not cause sufficient reduction of revealing power to be serious. It is, of course, not possible to generalise; the factors of each case, particularly the width of the road, the source lay-out, the spacing, and the road surface, will have an important bearing on the alteration of revealing power with height. This statement does not, of course, exhaust the question of mounting height, into which other factors enter as well; it is generally recognised that high mounting has an advantage over low mounting, which may not be wholly shown by the revealing power figures.

Importance of Revealing Power.

It was emphasised above that revealing power is not visibility as generally understood, and that the appearance of the lighted street was also very important. Probably the "visibility" in a lighted street will never be satisfactorily measured: but there are few problems in which any single figure of merit can be devised which will include, in proper proportion, all the desirable properties of the thing studied. The "visibility" in a street is as intangible as the qualities of a motor-car; each can be assessed

([17]) Wilson, Assoc. Publ. Ltg. Engrs.' Conference, 1937.

only by skilled judgment when all the facts are available. Revealing power is important in supplying some of the essential facts, and because a study of revealing power leads to a more complete understanding of the mechanism of street lighting, which helps in many of its problems.

APPENDIX I.

Calculation of Statistical Distribution of Object Brightnesses.

It has already been shown that in order to calculate revealing power it is necessary to know the numbers of objects which may be present anywhere on the road, the brightnesses of which lie below certain levels. It has also been pointed out that both the reflection factors of the objects and the illumination upon them will vary: a given level of brightness may be attained by various combinations of the two.

The total probability of occurrence of a given object brightness thus depends upon the two probabilities of occurrence of the appropriate level of illumination and reflection factor.

The problem is simpler when one considers the number of objects which do not *exceed* a given brightness. It can be more easily followed by an example. Suppose that the curve of illumination on vertical surfaces, E_v, has been taken (Fig. 3). Let the range of illumination be divided into convenient zones as before and as in Table I, and again find the proportions of the span over which the illuminations in each zone occur. The widths of the zones chosen are about 25 per cent. of the mean illumination in the zone.

Now for each illumination zone, the reflection factor can be found which must not be exceeded if some given brightness is not to be exceeded: it is convenient to calculate it for the mid-point of the illumination zone. For example, objects illuminated to 0.2—0.25 ft.-candle will not exceed 0.02 e.f-c. if their reflection factor does not exceed 8.9 per cent. (Line 8). These values are given in Column 3 of Table I. for a brightness of 0.02 e.f-c.

TABLE I.

Illumination Range. E_v. (e.f.c.)	Proportion of span over which this illn. occurs (=E_v. Proby.%) (from illn. curve).	Reflection factor necessary to attain 0.02 e.f.c.	Percentage of objects reflection factor of which does not exceed this value. (from curve, Fig. 6).	Number of objects in illumination range, brightness of which does not exceed 0.02 e.f.c. (% of total number) (col. 2 × col. 4).
1	2	3	4	5
0 —0.05	0%	80%	100%	0%
.05 — .065	4	34.8	98	3.9
.065— .08	11	27.6	95	10.5
.08 — .1	11	22.2	92	10.1
.1 — .13	18.5	17.4	87	16.1
.13 — .16	15.5	13.8	81	13
.16 — .2	14	11.1	75	10.5
.2 — .25	10.5	8.9	70	7.4
.25 —3	15.5	7.3	66	10.2
—	100.0	—	—	81.7

From data of the distribution of reflection factors, such as Fig. 6, it is possible to find the percentages of objects whose reflection factors do not exceed the values given in Column 3; for example, 98 per cent. of all objects lie below 34.8 per cent., and 95 per cent. lie below 27.6 per cent., and so on. These values are given in Column 4 of Table I.

Now, assume a large number of objects distributed uniformly on the road. Of these, 10.5 per cent., for example, will be illuminated to 0.2—0.25 ft.-candle, and of the 10.5 per cent., 70 per cent. will not be so light as to exceed a brightness of 0.02 e.f-c. Therefore, in this zone the number of objects, the brightness of which does not exceed 0.05 e.f-c.,

TABLE IIa.

Revealing Power: Objects %	Object Brightness not exceeding.	Necessary background brightness.
50	*.0054 e.f.c.*	*.022 e.f.c.*
75	*.0145*	*.032*
90	*.03*	*.055*
95	*.042*	*.07*
99	*.07*	*.11*

TABLE II. Object Brightness and Revealing Power

E_v. ft.-c.	E_v. Proby. %	Below .005 e.f.c.		Below .01 e.f.c.		Below .015 e.f.c.		Below .02 e.f.c.		Below .03 e.f.c.	
		p Proby. %	Objects %	p Proby. %	Objects %	p Proby %	Objects %	p Proby. %	Objects %	p Proby. %	Objects %
< .05	*0*	79	*0*	94	*0*	99	*0*	100	*0*	100	*0*
.05 — .065	*4*	69	*2.8*	87	*3.5*	94	*3.8*	98	*3.9*	100	*4*
.065— .08	*11*	66	*7.3*	81	*8.9*	91	*10*	95	*10.5*	100	*11*
.08 — .1	*11*	61	*6.6*	75	*8.2*	86	*9.5*	92	*10.1*	98	*10.8*
.1 — .13	*18.5*	55	*10.2*	70	*13.0*	79	*14.6*	87	*16.1*	94	*17.4*
.13 — .16	*16*	49	*7.9*	65	*10.4*	73	*11.7*	81	*13*	91	*14.6*
.16 — .2	*14*	40	*5.6*	61	*8.5*	69	*9.7*	75	*10.5*	86	*12.0*
.2 — .25	*10.5*	33	*3.5*	57	*6*	65	*6.8*	70	*7.4*	80	*8.4*
.25 — .3	*15.5*	25	*3.9*	50	*7.8*	61	*9.5*	66	*10.2*	75	*11.6*
.3 — .4		16		41		55		62		69	
.4 — .5		8		32		46		56		65	
.5 — .65		4		24		39		49		60	
.65 — .8				14		30		41		55	
.8 —1				7		20		33		47	
1 —1.3				4		13		26		39	
1.3 —1.6						7		15		31	
1.6 —2						4		7		19	
—	*100.5*	—	*47.8*	—	*66.3*	—	*75.6*	—	*81.7*	—	*89.8*

is $10.5 \times 70 = 7.4$ per cent., expressed as a percentage of the total number of objects. Proceeding in this way for each zone, one can find the total percentage of objects which do not exceed 0.02 e.f-c., by multiplying together the figures of Columns 2 and 4 to give Column 5, and summing Column 5. In this example, the total is 81.7 per cent.

The above example applied to one brightness only. It will be necessary in each installation to calculate the values for several brightness levels. But much of the calculation can be done once and for all, so that a standard table can be made, partly worked out, which can be used for all installations. Columns 1 and 2 apply to all brightness levels in a given installation. If the ranges taken in Column 1 are standardised, then the values in Columns 3 and 4 will also be standard for each brightness level, and there is indeed no need to tabulate Column 3 at all. For each brightness level, therefore, it is only necessary to tabulate Column 4 and leave space for filling in Column 5. The complete form is shown in Table II. To work out the curve of brightness probabilities, the values for Column 2 are filled in from the illumination curve, and these values multiplied by those corresponding to Column 4 (Table I.) for each brightness level to give figures corresponding to Column 5 (Table I.). The totals of these columns give the percentage numbers of objects, the brightness of which does not exceed the values given at the head of the columns. These percentages are plotted as a curve similar to Fig. 4, from which the object brightness corresponding to any given revealing power can be read.

The table (Table II.) will be suitable for all types of installations, except that it might have to be extended to cover very high illuminations. There is no need for further subdivision to take into account very low brightnesses and illuminations, because brightnesses less than 0.005 e.f-c. cannot be distinguished with certainty by a driver even against a completely black ground. In all practical lighting systems, therefore, objects of brightness less than this will appear as completely black.

Example.—A completely worked-out example, the figures of which correspond to the photograph shown in Fig. 9, is given in Table II., the figures filled in for the installation being in italics. The illumination curve is that of Fig. 3 and the curve of object brightnesses is that of Fig. 4.

APPENDIX II.

Calculation of Overall Revealing Power.

The most useful form in which revealing power can be expressed is probably as a distribution, but there may be instances in which it is desirable also to know the overall value. Such an overall figure would probably be valuable only as an adjunct to the distribution.

The basis of the overall revealing power is not quite the same as the mean value determined arithmetically from the distribution. The revealing power at a point in the field of view is the proportion of the number of objects *which can be seen against that point*, which will be adequately revealed. The overall revealing power is the proportion of all objects, considered as *scattered uniformly over the road*, which will be revealed. If a very large number of objects is considered as scattered uniformly in the space between the observer and the various parts of the field of view, it is obvious that there will be less objects intervening between him and the foreground parts than between him and the background; and from geometrical considerations alone a weighting is necessary in favour of the background. This is, of course, independent of any arbitrary weighting which might be desired to derive the visual safety of the installation.

Consider any narrow horizontal strip in the field of view. The number of objects which can be seen against it will be proportional to the distance away of the corresponding part of the background, and also to the length of the strip measured horizontally. Both these factors can be geometrically obtained from the perspective view.

In order to find the overall revealing power, divide the contoured photograph into horizontal strips. In any such strip, the width can be measured which lies within any one of the contours. The number of objects scattered uniformly over the road which can be seen against such a part of the strip will be proportional to the width of the strip measured in feet, and to the mean distance of the strip from the observer. If this is found for each contour, the differences between the numbers of objects for successive contours gives the numbers of objects included in the corresponding interval of revealing power; and this number, multiplied by the mean of the revealing powers at the two contours, gives the number of objects revealed in that part of the strip. Continuing in this way, the approximate overall revealing power can be

Calculation.

INSTALLATION:
Central mounting, T.P.=0.08 ft.c.

Below .04 e.f.c.		Below .06 e.f.c.		Below .08 e.f.c.		Below .1 e.f.c.		Below .15 e.f.c.		Below .2 e.f.c.	
p Proby. %	Objects %	p Proby. %	Objects %	p Proby. %	Objects %	p Proby. %	Objects %	p Proby. %	Objects %	p Proby. %	Objects %
100	*0*	100	*0*	100	*0*	100	*0*	100		100	
100	*4*	100	*4*	100	*4*	100	*4*	100		100	
100	*11*	100	*11*	100	*11*	100	*11*	100		100	
100	*11*	100	*11*	100	*11*	100	*11*	100		100	
98	*18.2*	100	*18.5*	100	*18.5*	100	*18.5*	100		100	
95	*15.2*	100	*16*	100	*16*	100	*16*	100		100	
92	*12.9*	98	*13.7*	100	*14*	100	*14*	100		100	
88	*9.3*	94	*9.9*	99	*10.4*	100	*10.5*	100		100	
82	*12.7*	92	*14.3*	96	*14.9*	100	*15.5*	100		100	
76		87		93		96		100		100	
70		80		88		92		98		100	
66		74		82		88		95		99	
61		69		75		82		91		96	
57		64		70		75		87		92	
49		60		66		70		80		87	
40		54		61		66		74		82	
31		40		49		61		69		75	
—	*94.3*	—	*98.4*	—	*99.8*	—	*100.5*	—		—	

found. Consider, for example, the installation shown in Fig. 9, and divide the carriageway into strips 100 ft. wide, i.e., from 100-200 ft., 200-300 ft., etc. On the photograph, these appear as narrow, horizontal bands. Take the width within each band which lies within each contour in turn, and tabulate the results as shown in Table III.

Had the revealing power been everywhere 100 per cent., the width covered by each contour would have been 30 ft., and the total would have been (30 × 150) + (30 × 250) + (30 × 350) . . . = 525. The overall revealing power is therefore 502/525, or 96 per cent.

* In the table, W is the width in feet of the part of the strip included within the contour concerned, and N = W.D/100, where D is the mean distance of the strip, e.g., 150 ft., 250 ft., etc. The last column is the product of the difference and the mean revealing power of the two contours, e.g., 62.5%, 82.5%, etc.

TABLE III.

Contour. Revealing Power %	Width covered in zone: 100′–200′ W*	100′–200′ N*	200′–300′ W	200′–300′ N	300′–400′ W	300′–400′ N	400′–500′ W	400′–500′ N	500′–600′ W	500′–600′ N	Total Objects.	Difference.	Total Revealed.
50	30	45	30	75	30	105	30	135	30	165	525		
												7	5
75	25	37	30	75	30	105	30	135	30	165	518		
												46	37
90	16	24	30	75	28	98	28	126	27	149	472		
												108	100
95	14	21	23	58	21	75	20	90	22	120	364		
												93	90
99	10	16	15	37	16	56	15	68	17	93	271	271	270

TOTAL REVEALED 502.

References.

Author	Periodical	Year	Vol.	No.	Page	Subject
Dunbar	Trans. I.E.S.(L)	1938	3			Necessary Brightness Contrasts
Smith	Trans. I.E.S.(L)	1938	3			Object Reflection Factors
English	Trans. I.E.S.(L)	1937	2	6	68	Visibility Tests
„ and Stroud	Light and Lighting	1937	30	10	287	Visibility Tests
	A.P.L.E. Conference	1937	—	—	—	
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v.d.Werfhorst	Philips Tech. Rev.	1937	2	8	238	Reflectivity of Clothing
Reid and Chanon	Trans. I.E.S.(A)	1937	32	2	187	Visibility Tests with Meter
„	Trans. I.E.S.(A)	1936	31	2	119	Visibility Tests on Models
„	Gen. Elec. Rev.	1935	38	—	522 579	Visibility Tests on Models
Waldram	J. Sci. Inst.	1936	13	—	352	Photographic Photometry
Bloch	J. Sci. Inst.	1936	13	—	358	
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	Physica	1936	3	10	1149	
Weavind and Herd	S. Afr. I.E.E. J.	1935	26	—	235	Visibility Tests
	Sci. Abs.	1936	—	461	—	
Luckeish and Moss	Trans. I.E.S.(A)	1935	30	7	531	Visibility Meter
	J. Frankl. Inst.	1935	220	4	431	
	Trans. I.E.S.(A)	1937	32	1	19	(See Discussion)
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NECESSARY VALUES OF BRIGHTNESS CONTRAST IN ARTIFICIALLY LIGHTED STREETS*

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(Paper read on Tuesday, November 8th, 1938.)

SUMMARY.—Experiments conducted in a street lighting installation in which the road surface was uniform in brightness have given a curve relating the brightness of the background to the difference in brightness between an object and the background which it is necessary to have for safe driving at 30 m.p.h. This standard curve applies only to the case of installations in which there is no glare from the street lamps.

Although the background in most street lighting installations is not uniform in brightness, the results of other experiments have been used to show that, in practice, no modification of the standard curve is necessary on this account provided that the road is dry.

If an installation is not free from glare, the necessary brightness difference between an object and its background will be greater than that given by the standard curve. The curve can, however, still be used if, in deriving this brightness difference, all brightnesses of the background are assumed to be increased by a certain amount. Methods of evaluating this correction for glare have been described.

The results of this work can be applied to the problem of determining what proportion of practical objects will be revealed to the driver of a car by any region of the background in a street lighting installation.

Introduction.

The chief demand that a motorist makes of a street lighting installation is that it should reveal any object which is, or may become, a source of danger to him, and at such a distance that he has adequate time to take the necessary action. If in any position in the installation and for any position of the driver such an object cannot be detected, then the installation falls short of perfection. It is assumed that the use of headlights in artificially lighted streets should neither be necessary nor permissible.

A method [1] has recently been proposed for assessing the revealing power of an installation, i.e., the extent to which an installation makes objects visible to road users. This method differs from others which have been used in the past in that it recognises the fact that revealing power should not be concerned only with the appearance of specified objects in particular positions in the installation.

Methods which have taken this line of approach have touched only the fringe of the problem. In a practical case the driver may be called upon to detect against any region of the background any one of a large number of possible objects which may differ considerably in size or shape and which may have brightnesses which differ by as much as 50 : 1. This large range of object brightness is the result of the change in illumination on vertical surfaces through a span of the installation and of the range of reflection factor which practical objects may have.

To obtain a true idea of the revealing power of an installation, it is necessary to determine in what proportion of cases the object will be seen when account is taken of all possible object positions in the installation and of all possible object reflection factors.

The proposed method [1] of assessing the revealing power of an installation shows that from a consideration of (a) the variation in vertical illumination from point to point in the installation, and (b) the variation in reflection factor of practical objects [2], one can determine the percentage number of possible objects having a given brightness which the driver may be called upon to detect against any region of the background. The brightness of the background can be easily obtained [3, 4].

In this approach to the problem the investigator would so far be concerned only with the physical properties of the installation and the objects which may occur in it. To obtain the revealing power of the installation he must be able to say which object brightnesses will be revealed to the motorist. In other words, he must know the least difference in brightness between an object and its background which must exist before the object will be detected.

It is well known that this requisite difference in brightness will depend on a number of factors, of which the brightness of the background is an important example. These factors are listed in the next section.

The experimental work described in this paper was carried out with the object of supplying the investigator with the data which he required and which would enable him to determine the revealing power of any street lighting installation without further experimental work on object visibility. His own experimental work would be restricted to the measurement of certain characteristics of the installation, such as the brightness of the backgrounds against which objects would be seen and the distribution of illumination on vertical surface. From a knowledge of these characteristics and the results of the experimental work described here, the revealing power of the installation would then be found [1].

Object Visibility.

The least difference in brightness between an object and its background which must exist before

* The work which forms the subject of this paper was contributed by the author to an investigation by the Experimental Panel of the Ministry of Transport Departmental Committee on Street Lighting into the question of the Measurement of Visibility. The work was commenced in October, 1935, and was reported to the Committee in June, 1936. The paper should be read in conjunction with papers by Mr. J. M. Waldram and Mr. F. C. Smith, describing their contribution to the problem.

the object will be perceived has been the subject of a great deal of work in the laboratory ([5, 6, 7, 8]). Confining ourselves at the moment to the case where the object and its background are both uniformly bright, this least or threshold difference in brightness has been found to depend on—

(a) the angular size of the object;
(b) the brightness of the background;
(c) the colour of the object and of the background.

These factors are all independent of the observer, and whether his eyes are capable of detecting the object under a specified set of physical conditions has been found to depend on—

(d) their adaptation level;
(e) their previous light history;
(f) the degree of glare;
(g) the amount of distraction to which the observer is subjected.

The last factor is of great importance. It might seem reasonable to suppose that for corresponding brightness conditions in the street it would be possible to say from laboratory data whether an object would be detected by a driver. This is not the case, however. The threshold value depends very largely on the stringency of the experimental conditions, and the fact that the driver has not only to control a moving vehicle but is also subjected to distractions not experienced in laboratory experiments, will make his threshold values much larger than laboratory results would indicate.

Experimental Determination of Critical Contrast.

Although the threshold values determined in the laboratory cannot be applied to a consideration of the visibility of objects in a street lighting installation, the above summary of laboratory results does indicate the factors which will affect the visibility of an object in the street. The most important single factor is the contrast between the object and its background, and it was with this that the experimental work was first concerned. (For the purpose of this paper, contrast is defined as the difference between the brightness of the object and that of the background against which it is seen.) The most direct method of attack seemed to be to obtain an experimental curve relating the threshold contrast applicable to the street lighting case to background brightness for a fixed set of the other factors affecting visibility, and then to consider what effect varying each of these factors would have on the curve obtained.

It has already been mentioned that the threshold contrast is greatly influenced by the exact nature of the experimental conditions. It seemed obvious, therefore, that if the threshold contrasts obtained in the experimental work were to be used in determining the revealing power of an installation for the driver of a car, then they would have to be obtained by car drivers under practical street lighting conditions.

There was, however, a serious difficulty to be overcome before the threshold values could be measured in this way. It is a matter of common observation that the road surface in a street lighting installation is usually non-uniform in brightness, and as a result of this brightness diversity an object may at any instant overlap a light and dark area of the street so that not necessarily the whole of the object will present the same brightness contrast. In addition, as the driver moves through the installation the brightness of any particular point in the installation is continually changing and the background of even a stationary object is not constant in brightness. It was difficult to see, therefore, how it would be possible in the street to obtain, experimentally, values of the threshold contrast for different background brightnesses using an object of reasonable size.

The author was fortunate in that an experimental installation was placed at his disposal which was so designed as to overcome this difficulty. This installation was half a mile long and was practically straight. The lighting fittings were arranged in a triple suspension, i.e., one row of fittings over each kerb and one down the centre of the roadway, with a spacing of 120 ft. The fittings were mounted at a height of 25 ft. and consisted of asymmetric refractor units with 300-watt lamps. The carriage-way was 30 ft. wide and had a concrete surface. With this number and arrangement of sources the road surface itself gave a very good approximation to a uniformly bright background. The voltage of the lamps could be varied so as to adjust the brightness of the road surface to any desired value. As the installation was open to traffic, the experiments could be carried out under normal driving conditions.

The visibility criterion to be used in this work required some consideration. As the results were to be used to assess the revealing power of installations, a threshold contrast hardly seemed adequate, since this would only give the object a 50 per cent. chance of detection. The object can be said only to be revealed when the probability of detection is practically 100 per cent. It was finally decided to adopt as a criterion that contrast which, in the opinion of the observer, was just sufficient for safe driving at 30 m.p.h. This contrast will in future be referred to as the " critical contrast."

The object used for the test consisted of a disc 1.5 ft. in diameter mounted at a height of 2 ft. above the road surface. The brightness of the disc could be varied by changing its position in the span, the vertical illumination distribution providing a possible 5 : 1 range in object brightness. The object positions selected were such that the object would always be seen against the road surface by the driver of a car. The observer drove through the installation at a speed of 30 m.p.h. and was asked to state at which object position he considered the object contrast just sufficient for safe driving at that speed. Only one object contrast was presented in each run, but in successive runs this contrast was alternated about the critical contrast in a bracketing method until the required object position was ascertained. It was stipulated that the observer should form his opinion before he was within 100 ft. of the disc, as this was considered the minimum distance at which a driver could take effective action. The object was always seen as dark on a lighter background, as this is the important case in street lighting. The critical object position having been determined, measurements of

the object and road brightnesses enabled the critical contrast for that value of the background brightness to be obtained. The experiment was then repeated with the same observer using different background brightnesses.

The results for ten observers who have carried out the tests over a range of background brightness of

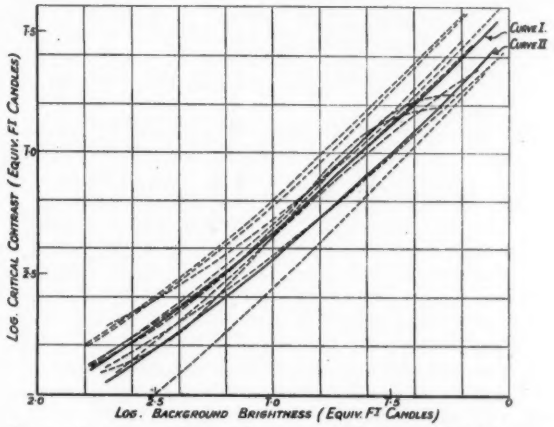

Fig. 1. Variation of Critical Contrast with Background Brightness.

from approximately 0.03 to 1.0 equivalent foot-candles are given in Fig. 1. The mean curve is shown as a continuous line (Curve I). With the exception of those obtained by one observer all the results lie within 40 per cent. of the mean curve. The outstanding observer appeared to have an exceptionally high visual performance and was known to drive comfortably under extremely bad lighting conditions. Considering the nature of the tests these results were very satisfactory, and it seemed doubtful if much would be gained by extending the tests unless a very large number of observers were used.

Other Factors Affecting Visibility.

1. Non-Uniformity of Background Brightness.

The critical contrast measurements described above were made using as uniformly bright a background as possible. In general, the brightness distribution of the roadway in any street is made up of a "mosaic" of light and dark patches, and it is to be expected that the critical contrast in a dark patch will be increased as a result of adjacent higher brightnesses. This point obviously required experimental investigation.

As it was impossible to conduct experiments in an actual patchy street, some artificial means of creating a patch had to be considered. The tests were finally conducted using a screen 3 ft. square erected vertically in the carriage-way. Viewed from a car, the screen appeared as a dark patch on the roadway, the remainder of the road surface being made of a uniform brightness with the triple suspension lighting system. This surround brightness could be varied by means of the voltage control on the lamps, and the patch brightness was kept constant by either changing the position of the screen in the span or changing its reflection factor, or both. An object in the patch was represented by one of a series of cards 1 ft. square and of graded reflection factor which could be pinned on to the screen. The observer driving through the installation was asked to exercise the same criterion as in the initial critical contrast tests as to the visibility of the object in the patch. In this way the critical contrast for an object in the patch could be obtained for different surround brightnesses, the patch brightness being constant.

The results obtained by ten observers are given in Fig. 2, the mean curve again being represented by the continuous line. The spread of the results is comparable with that given in the first tests, and it will be seen that for the patch brightness used (0.09

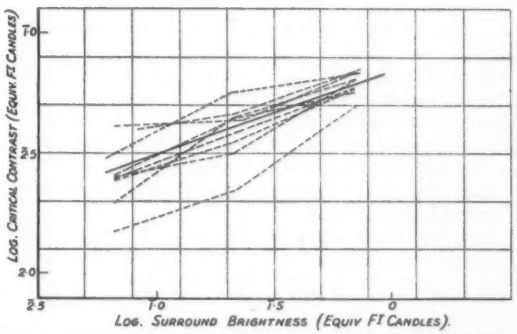

Fig. 2. Effect of Surround Brightness on the Critical Contrast in a patch.

equivalent foot-candles) the critical contrast for an object in the patch is almost exactly doubled as the surround brightness is increased from the patch brightness to ten times the patch brightness.

2. Object Size.

The standard object used in the critical contrast tests consisted of a circular disc 1.5 ft. in diameter. This size of object was used simply for convenience and was not intended to be typical of the size of object usually met with in the street. In order to apply the curve obtained for the standard object to any practical object, it is necessary to consider the effect of object size on the critical contrast at different background levels. It must be recognised in this respect that frequently only part of an object will be satisfactorily revealed to a driver, and that in these circumstances the effective size of the object is reduced to that portion of it which is revealed.

The four objects used for these experiments all had one dimension equal to 1.5 ft., the other dimension being 0.75, 1.5, 3.0, and 4.5 ft. respectively. These objects were considered to be representative of the types usually met on the road, the largest being equivalent to the main bulk of a pedestrian and the smallest about the size of a cat. The critical contrast for each object was determined in a manner identical with that described for the standard object.

The mean results obtained by seven observers are shown in Fig. 3, the critical contrast being plotted against the variable linear dimension of the object. The tests were conducted at three brightness levels

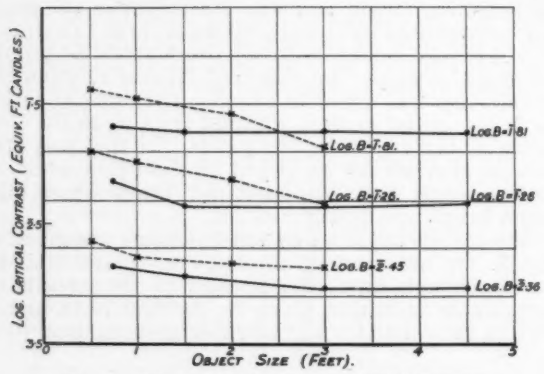

Fig. 3. Effect of Object Size on Critical Contrast.

covering a range of 28 : 1, the maximum brightness used being 0.65 equivalent foot-candles.

Some preliminary tests were also made by three other observers using objects which were square. These results are shown in Fig. 3 by the dotted lines. For these objects, the horizontal scale will refer to the side of the square.

It will be seen that for the objects which all had one dimension equal to 1.5 ft., the critical contrast is approximately independent of the other dimension, provided that the latter is not less than 1.5 ft. On the other hand, in the case of the square objects, the critical contrast increases as the side of the square decreases. This result agrees with the conclusion reached by Abney (8) that the threshold contrast is mainly determined by the smaller dimension of the test object. The two object size curves appropriate to the same background brightness in Fig. 3 do not intersect at a value of 1.5 on the horizontal scale because the tests with the square objects were carried out by the three observers who always obtained the highest values of critical contrast.

3. Glare.

The critical contrast tests were all carried out with the observer's eyes exposed to any glare which the street lamps might produce. As the range of background brightness used in this work was obtained by decreasing the voltage on the street lamps, the glare from the latter had an approximately constant effect on the critical contrast whatever the brightness level. Preliminary experiments had shown that the critical contrast was increased by approximately 7 per cent. as a result of the glare.

In practical installations, however, lamps at a constant voltage produce a "mosaic" of light and dark patches, and the glare from the lamps will be most harmful to the visibility of objects when the latter are to be seen against the darkest part of the background.

It was originally intended that experiments should be carried out in a number of streets to find the extent to which the critical contrast was affected by the glare from the street lamps. Unfortunately, the tests had finally to be restricted to one installation, so it was decided to select one in which the glare was as serious as was ever likely to be encountered in street lighting. This installation had a central suspension of fittings of high magnification factor, a spacing of 240 ft. and a mounting height of 20 ft.

The artificial patch used in considering the effect of surround brightness was again employed to overcome difficulties arising from the patchy nature of the brightness distribution, and was given a brightness equal to that of the darkest part of the carriage way, viz., 0.05 equivalent foot-candles. The critical contrast in the patch was determined both with and without the driver's eyes shielded from the glare of the street lamps.

The results for eight observers showed that on the average the effect of the glare was to increase the critical contrast by 28 per cent. for an object seen against the darkest part of the road surface.

4. Miscellaneous Factors Affecting Visibility.

The effect of colour, the previous light history of the observer's eyes, and the fact that while the observer is searching for objects his eyes have to traverse a field which is non-uniform in brightness, are other factors which may affect object visibility.

As far as colour is concerned, the lowest visibility will occur with "black-and-white vision," and as this very commonly occurs and has been used exclusively throughout the tests, it is probably sufficient to recognise that the visibility of a highly-coloured object will be better than the experimental results would indicate. This is especially true at high brightness levels.

The effect of non-uniformity of brightness in the visual field on the adaptation level of the observer's eyes is not likely to be important unless the brightness diversity is very high. Laboratory results (9) have shown that if an observer is viewing alternately two brightnesses which are in the ratio of 10 : 1, the threshold in the region of either brightness one second after the switch-over to that brightness occurs is negligibly different from that which would be obtained if his eyes were completely adapted to that brightness.

The previous light history of the observer's eyes is a factor over which there is no control.

Discussion of Experimental Results.

The experimental work has given a curve relating critical contrast to background brightness over a large range of the latter for a background of uniform brightness and for a test object of 1.5 ft. diameter. It is necessary now, in the light of the subsequent work, to consider what modifications must be made to this curve before it can be applied to the task of determining the revealing power of any installation.

The individual critical contrast curves given in Fig. 1 represent the results obtained by each observer on a particular occasion, and in all cases it was the first time that the observer had participated in a test of this nature. In subsequent work on the effect of object size on the critical contrast, other results were obtained by the same observers for an object of linear dimensions equal to 1.5 ft. The mean results obtained in this work are also shown in Fig. 1 (Curve II.). It will be seen that this curve is parallel to Curve I., but the values of critical con-

trast are some 20 per cent. lower. It has been decided to take the mean of the two curves as the true critical contrast curve for the experimental installation, as this mean will include not only the variation between individuals but also the variation obtained by each individual on different nights. This mean curve, corrected for the glare from the street lamps, is given in Fig. 4. The curve is therefore applicable to a uniformly bright installation in which there is no glare from the street lamps, and will be referred to as the standard critical contrast curve.

It has been stated previously that in the determinations of critical contrast the observers were prohibited from assessing the visibility of the object at distances less than 100 ft. For convenience in marking this limiting distance, the test object was always placed in the same span of the installation. As it might be felt that the use of a single test object which always occurred in the same span made the experiments a little artificial, a second test was organised along different lines. Four identical objects were distributed throughout the uniformly bright installation, and were given brightness contrasts which were 30 per cent. higher, 10 per cent. higher, 10 per cent. lower, and 30 per cent. lower than the value given by the mean critical contrast curve for the experimental installation and for the appropriate road brightness. Eleven observers took part in the test, only three of whom had been concerned in the previous work. The observers drove through the installation at a speed of 30 m.p.h., and were asked to state whether each object contrast was more than, equal to, or less than that required for safe driving at that speed. The contrasts were arranged in a random order, which was changed for each of the three road brightnesses used. The latter covered the range of the critical contrast curves in Fig. 1. The results showed that for each of these three road brightnesses, ten of the eleven observers were of the opinion that the value of the brightness contrast just sufficient for safe driving was either 10 per cent. higher or 10 per cent. lower than the value deduced from the previous experimental work. A contrast 30 per cent. higher was always considered very satisfactory, while ten observers unanimously condemned a contrast of 30 per cent. lower. The exceptional observer was a professional driver, who considered all the contrasts presented to be adequate.

It would appear, therefore, that the standard critical contrast curve given in Fig. 4 can be adopted with some confidence as the curve applying to a uniformly bright installation in which there is no glare from the street lamps. The modifications to be made to this curve are discussed below.

1. Extraneous Glare Sources.

The determinations of critical contrast were all made in the absence of glare from opposing headlights. It was originally intended that the results should include the effect of opposing sidelights, but it was found that there was considerable difficulty in doing this. On many occasions sidelights were encountered which were so glaring that the observer found it quite impossible to continue the run, and it is a matter of common observation that it is sometimes extremely difficult to decide whether the lights of an oncoming car are sidelights or headlights. Measurements of the candle-power of two sidelights, one consisting of a 6-watt lamp in a parabolic reflector of 3-in. diameter and fitted with a diffusing front glass, and the other consisting of a 6-watt lamp in a cone-shaped whitened box with diffusing front glass, gave peak candle-powers of 1,200 and 8 respectively.

Fortunately, the great majority of cars are now being fitted with the second type of sidelight. There is no appreciable glare from these sidelights and the observers were not inconvenienced by their presence. The standard critical contrast curve can be taken to include the glare effects from such sidelights.

2. Effect of Object Size.

The experimental work has shown that if the test object has one dimension equal to 1.5 ft., then the critical contrast is independent of the other dimension, provided that it is not less than 1.5 ft.

A driver in the street is mainly interested in objects which are between 100 ft. and 300 ft. ahead. As this is precisely the region over which the observers in the above tests would be exercising their criterion as to the visibility of the object, then in considering the revealing power of an installation the standard critical contrast curve may be taken as applying to the case of objects whose smaller dimension is equal to 1.5 ft.

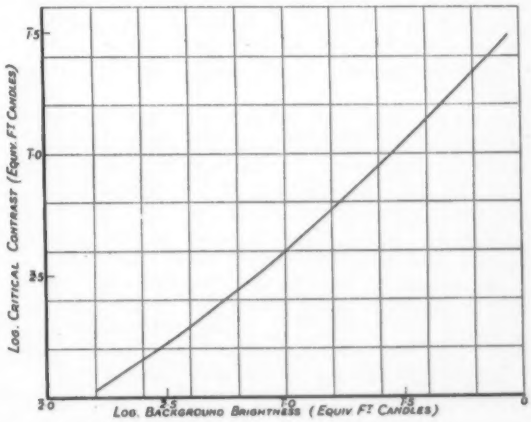

Fig. 4. Standard Critical Contrast Curve.

3. Effect of Surround Brightness.

The standard critical contrast curve given in Fig. 4 refers strictly only to the case where the background is uniform in brightness. It was shown in later experiments that if an isolated dark patch in the roadway was considered, the remainder of the roadway being at a uniform brightness equal to ten times that of the patch, then the critical contrast in the patch had double the value appropriate to a field of uniform brightness equal to that of the patch.

This increase in the critical contrast for an object in the patch is due to the fact that the surrounding high brightness acts as an extended glare source.

Laboratory work ([6, 7]) has shown that the increase in the threshold contrast due to glare depends on—

(i) the angles θ_1, θ_2, etc., between the observer's direction of vision and the lines joining his eyes to the glare sources;

(ii) the illuminations E_1, E_2, etc., which the glare sources produce in the plane of the observer's eyes.

The threshold contrast for an object surrounded by a brightness B and in the presence of glare specified by θ_1, θ_2, etc., E_1, E_2, etc., has the same value as if the object were surrounded by a brightness β, where

$$\beta = B + K\left[\frac{E_1}{\theta_1^2} + \frac{E_2}{\theta_2^2} + \dots\right]$$

K being a constant. This equation is known as the equivalent background formula. The best experimental value for K is 10π, when θ is measured in degrees, β and B in equivalent foot-candles and E in foot-candles.

There is no reason to suppose that the equivalent background formula cannot be applied to the critical contrast as well as to the laboratory threshold contrast, although it does not necessarily follow that the constant K will have the same value. In applying the formula to a consideration of the surround brightness effect in practical installations the exact value of K is immaterial, since it is inherently determined by the experimental work described earlier in this paper.

Let us consider the magnitude that the surround brightness effect is likely to have in a practical case. The brightness pattern on the roadway will be determined largely by the arrangement of the light sources. The three most common arrangements are the diagonal, opposite, and central suspensions. In the case of the diagonal and opposite suspensions, the traffic lanes are the brightest regions of the roadway, regions of lower brightness lying along the centre of the road and along the kerbs. In a central suspension, the highest brightness occurs near the centre of the road, the brightness falling off towards the kerbs.

Generally speaking, one would expect the effect of surround brightness to be greatest when an area of low brightness occurred at the centre of the road in an installation with a diagonal or opposite suspension, since this dark area would be flanked on both sides by regions of high brightness.

For the purpose of calculation an installation of this type has been selected. A photograph of the installation is shown in Fig. 5. The installation has a diagonal suspension, and was chosen because the low mounting height (15 ft.) accentuated the central dark area. The road brightness has been contoured in equivalent foot-candles.*

Consider the small circular patch which has been shaded in the photograph and which occurs at the centre of the road inside the 0.06. contour. The angular diameter of the patch is $\frac{3}{4}°$, i.e., approximately the size of the patch used in the experimental work. If any circular zone concentric with the patch has an angular width $d\theta$, a mean angular radius θ, and the average brightness in the zone exceeds that in the patch by an amount B, then the critical contrast for an object in the patch will be that appropriate to a road brightness β, where

$$\beta = 0.06 + \frac{2\pi K}{57.3^2}\ \lambda_1$$

$$\lambda_1 = \int \frac{B d\theta}{\theta}$$ where the integration extends over the whole of the road surface outside the patch. Suppose now that the whole of the road surface with the exception of the patch is raised to a brightness of 0.6 equivalent foot-candles, i.e., ten times the brightness of the patch. Then a second integral λ_2 can be evaluated, and it is found that $\frac{\lambda_1}{\lambda_2} = 0.05$.

It follows that the higher brightness surrounding the selected small patch in Fig. 5 will increase the critical contrast for an object in the patch by an amount equal to 5 per cent. of that determined in the experimental work for a surround brightness equal to ten times the patch brightness. In other words, the critical contrast will be increased by 5 per cent. It appears, therefore, that the values of critical contrast applicable to the non-uniform brightness distribution of a practical installation are negligibly different from the values determined on a uniformly bright roadway. This is a welcome simplification of the problem, since the critical contrast

Fig. 5.

*The author is indebted to Mr. J. M. Waldram for permission to reproduce this photograph.

curve given in Fig. 4 can be applied to an installation without consideration of the brightness distribution peculiar to the installation.

The reason for the smallness of the effect can be seen from Fig. 5. In the experimental work the patch was wholly surrounded by a uniform high brightness, but in a practical case not only does the brightness increase gradually outside the patch, but the highest brightnesses of the roadway occupy only a small proportion of the area of any zone surrounding the patch.

The above argument applies only to a dry road. In the case of a wet road, the bright streak formed by each light source has a brightness which is large compared with the maximum brightness of the road in a dry state.

These bright streaks will certainly have an appreciable effect on the visibility of objects seen against the intermediate dark areas. At the moment we are concerned only with the case of dry roads, but if the revealing power of any region of the background in a wet road were required, then the effect of the bright streaks on the critical contrast for objects seen against that region would have to be evaluated.

4. Effect of Glare from Street Lamps.

Although it has been shown that the standard critical contrast curve can be applied to any installation in which there is no glare from the street lamps and in which the road is dry, the curve has still only a limited application, since few installations are entirely free from glare.

It will have been gathered from the previous section that the effect of the glare from the street lamps will be to make the critical contrast for an object seen against a brightness B in the installation that which the standard critical contrast curve would give for a brightness β, where

$$\beta = B + K\left[\frac{E_1}{\theta_1^2} + \frac{E_2}{\theta_2^2} + \text{---}\right]$$

E_1, E_2, etc., are the illuminations produced in the plane of the observer's eyes by the street lamps, and θ_1, θ_2, etc., are the angular separations of the street lamps from his direction of view.

$$\text{The glare term } \lambda = K\left[\frac{E_1}{\theta_1^2} + \frac{E_2}{\theta_2^2} + \text{---}\right]$$

has not a unique value for any street lighting installation, but will vary with the position of the driver in the span and with his direction of view.

In considering the revealing power of an installation, one or more typical positions of a driver would probably be selected. The lateral position of the driver would normally be taken as 10 ft. from the nearside kerb and his eye height as 5 ft., in accordance with the convention adopted by the International Commission on Illumination, in 1935. As many longitudinal positions as seemed necessary would then be considered.

Whatever method was used to determine the value of λ, it would be a long and tedious task to find, for a particular view point the exact value of this quantity for all directions of view in the installation. The problem can be simplified, however, as for most practical purposes it would probably be sufficient to select a particular direction of view which gave a glare term equal to the mean value for the installation. A consideration of installations with different mounting heights, spacings, and types of suspension has shown that for a driver 10 ft. from the nearside kerb a direction of view towards a point on the road surface 500 ft. ahead and 10 ft. from the nearside kerb will give a glare term which is a close approximation to the required mean.

To this degree of approximation, the correction to be applied to the critical contrast curve resolves itself into the evaluation of λ for a single direction of view.

As the method of determining the revealing power of an installation ([1]) for a particular view point involves a photograph of the installation being taken from that view point, it is a simple matter to obtain from this photograph the angular separation of the light sources from the selected direction of view of the driver. If the candlepower of each light source in the direction of the observer's eyes can be determined, then the glare term can be computed. Strictly speaking, these candlepowers should be measured in the installation, since bad alignment of the fittings or a reduction in candlepower under service conditions may prohibit the use of the maker's polar curve. This would mean a considerable amount of work. There could be no objection to this procedure if the corrections to be applied to the critical contrast seriously affected the calculated values of revealing power in an installation. It was found in the experimental work that in a street which was considered very glaring, the critical contrast for an object seen against the darkest part of the roadway was increased by 28 per cent. as a result of the glare from the street lamps. In most installations, the corrections to be applied for glare would be small and the amount of work required to obtain them would be considerable. This does not mean, however, that the question of glare can be neglected entirely, since it would obviously be unfair to assume that in some installations the visibility of objects was unaffected by the glare from the street lamps.

The practical engineer would probably require some much more rapid method which would give him, at least approximately, the value of the glare term in an installation. An attempt has been made to design an instrument which actually measures the change in a threshold contrast as a result of glare ([10, 11]). With such an instrument, the glare term can be deduced without any reference either to the position of the street lamps in the visual field of the observer or to the candlepower of the sources. Unfortunately, it was found that in practice elaborations had to be made to the instrument which rather defeated the simplicity originally aimed at.

The correction to be applied to the critical contrast for the glare in an installation is therefore generally small, but difficult to evaluate. If the installation in which the effect of glare was studied experimentally represents an extreme case of glare, then it is probable that the correction to be applied to the critical contrast in any installation could be

obtained sufficiently accurately by dividing installations into three groups representing increasing steps of glare, and by associating a definite factor with each group. The multiplication of the minimum brightness in an installation falling in a particular group by the factor for that group would give the appropriate value of the glare term. If, for example, the groups included installations in which the critical contrast for objects seen against the darkest part of the roadway was increased by 0 per cent. to 10 per cent., 10 per cent. to 20 per cent., and 20 per cent. to 30 per cent., then the factors for the groups would be 0.05, 0.15, and 0.25 respectively. The first group would include installations in which the glare had little noticeable effect on object visibility, and the last group would include installations in which the glare was obviously bad. It is possible that some simple test could be evolved which would assign any installation to a particular group.

Whether the mean glare term for an installation is determined by some such approximate method or by the more accurate methods described previously, the critical contrast curve will be corrected in the following way. The value of the glare term will be added to all background brightnesses in an installation, and the critical contrast will then be read off the standard critical contrast curve for these corrected brightnesses.

Conclusion.

The experimental work has given a curve (Fig. 4) relating the brightness contrast between an object and its background which it is necessary to have for safe driving at 30 m.p.h. to the background brightness for an installation in which the background is uniform in brightness and in which there is no glare from the street lamps. The curve refers to an object which is uniform in brightness, and which has no dimension less than 1.5 ft.

It has been shown that the fact that most installations are not uniform in brightness does not invalidate the use of the curve, since the higher brightnesses in an installation have a negligible effect on the critical contrast for objects seen against the darkest parts of the background. This is only true for a dry road. The curve can therefore be applied to any installation in which the road is dry, and in which there is no glare from the street lamps.

If an installation is not free from glare, then the critical contrast for an object seen against any brightness B is that which the critical contrast curve for a glareless installation would give for a brightness β, where

$$\beta = B + \lambda.$$

λ is the mean glare term for the installation, and methods of evaluating it have been described.

The experimental work has provided a simple tool in the shape of a single curve which is used in conjunction with modified background brightnesses for determining which objects will be revealed against any region of the background in a street lighting installation. If the results are used in conjunction with easily measurable characteristics of an installation, such as the brightness distribution of the background and the distribution of illumination on vertical surfaces in the way described by J. M. Waldram (1), the revealing power of any region of the background in an installation can be obtained, provided that the statistical distribution of the reflection factors of practical objects has been predetermined (2). The revealing power so obtained would refer to the driver of a car travelling at 30 m.p.h., and to objects which were not nearer to the driver than 100 ft. All objects in the street would be assumed to be stationary, and over at least a certain minimum area uniform in brightness. Since most objects in the street are not stationary and since, especially at high brightness levels, they may be perceived by brightness contrasts over their surfaces, the revealing power will generally be somewhat higher than that deduced from the experimental results. The primary object of this work was to obtain results which could be used for studying the effects of such factors as mounting height, spacing, and types of distribution, and for this purpose the limitations imposed on the objects are not likely to mislead the investigator.

The standard critical contrast curve has been replotted in Fig. 6, the ratio F of the critical contrast to the background brightness B being plotted against log. B. It will be seen that when B is equal to 1.0 equivalent foot-candles, F is equal to 0.33. As B decreases, the value of F increases only slowly until B is less than 0.1 equivalent foot-candles. Below this value of B, F increases more rapidly, and when B is equal to 0.02 equivalent foot-candles, F is equal to 0.61. A point must eventually be reached at which F approaches close to unity. Background brightnesses which give such values of F should not occur in street lighting installations, since the visibility of objects against such backgrounds would be unsatisfactory, even if the objects were of the lowest possible reflection factor. A consideration of Fig. 6 would indicate that it is unwise to permit lower brightnesses than 0.01 equivalent foot-candles, especially if the installation is not free from glare. It is interesting to note in this connection that observers who drove down a roadway which was uniform in brightness and who were asked to state what was the lowest brightness value at which they felt sure that the road was clear (i.e., that no objects were present) gave this value as 0.03 equivalent foot-candles

Fig. 6 may be used to deduce what the effect of increasing the power in an installation would be provided that the distribution was unaffected. Such an effect could be obtained by increasing the voltage on the lamps. When the installation has a low power, the revealing power will be high only in the bright regions close to the light sources. In the darker regions the revealing power will be very low. As the power is increased, the revealing power will increase most rapidly in the darker regions of the street. When the brightness of any region reaches a value of about 0.1 equivalent foot-candles, a further increase in power will not materially alter the revealing power in that region. When the power is such that the brightnesses of all backgrounds in the installation are in excess of 0.1 equivalent foot-candles, the revealing power of the installation as a whole will become approximately independent

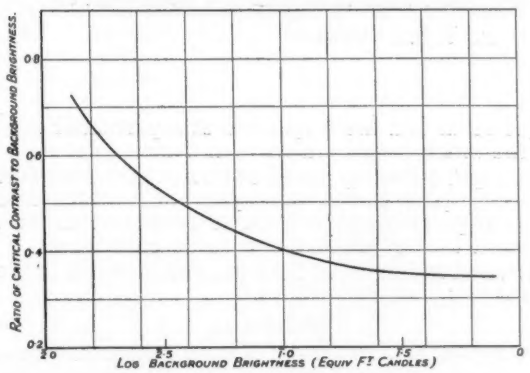

Fig. 6. Variation of F with Log B.

of the power. The latter fact requires some explanation, since it is almost certain that drivers would consider increases in the background brightness above 0.1 equivalent foot-candles advantageous. The reason for this is probably that the critical constant curve, by definition, applies to the case of objects which are uniform in brightness. Practical objects are seldom flat, and shadows cast by one part on another produce a non-uniformity of brightness even on objects which have a constant reflection factor. The perception of brightness contrasts on the surface of an object probably plays an increasingly important part in its detection, the higher the brightness level. For this reason the revealing power in an installation may still be increasing even when the experimental results indicate that it becomes independent of the power. Until more is known of this effect, it is desirable that the experimental results should be confined to the consideration of such problems as mounting height, spacing, and types of distribution, and not used for the comparison of the revealing power in installations which differ widely in brightness level.

Acknowledgements.

The experimental work described in this paper was necessarily conducted at night under conditions which were often trying and somewhat hazardous. The author is therefore deeply grateful to Mr. B. J. W. Oram for his assistance in all the experimental work, and to those members of the Ministry of Transport, General Electric Company, Gas Light and Coke Company, and National Physical Laboratory, who willingly gave their services as observers.

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REFLECTION FACTORS AND REVEALING POWER

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(Paper read on Tuesday, November 8th, 1938.)

The work which forms the subject of this paper was part of that contributed by the author to an investigation by the Experimental Panel appointed by the Departmental Committee of the Ministry of Transport on Street Lighting.

The significance of object brightness in relation to revealing power has been made clear in the papers by Dunbar and Waldram.

In order to calculate the probability of an object of any given brightness appearing under a given set of lighting conditions, it is necessary to have a knowledge of the frequency with which any given reflection factor may occur.

Since clothing is largely a matter of individual taste, a considerable number of measurements are necessary in order that the final curve showing the distribution of reflection factors shall be truly representative.

This paper describes:

(a) The methods adopted for measuring the reflection factors of clothing.

(b) The manner in which the results were combined for use in the calculation of revealing power.

Methods of Measuring Reflection Factors.

Observations were carried out by three independent sets of observers so that a large and varied number of results should be available.

METHOD I.

The article of clothing was illuminated by a headlight beam and the brightness of a particular region of the article measured with an illuminometer.

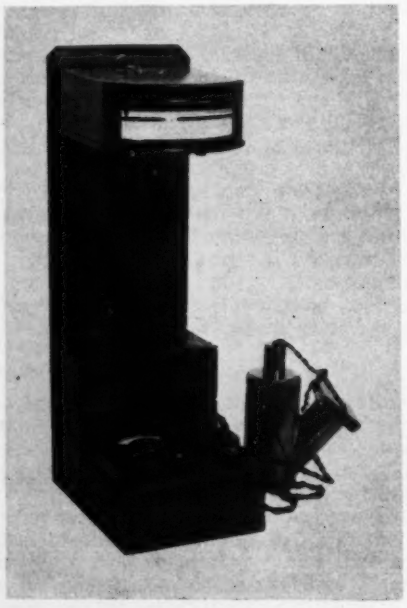

Fig. 1

An opal diffusing screen of known reflection factor was then placed over this region and a measurement of its brightness was then made. These measurements enabled the reflection factor to be calculated.

Normal incidence of the light and an angle of view of 30° was used throughout.

METHOD II.

A series of surfaces of known reflection factors was prepared, and compared directly under normal lighting conditions with the clothing to be measured.

It is not claimed that this method is so precise as the other methods described in this paper.

METHOD III.

A simple and convenient apparatus was constructed for the purpose, and is illustrated in Fig. 1.

In Fig. 1 a cylindrical brass tube of about 3-in. diameter was open at the lower and closed at the upper end by a 6-watt bulb and reflector from a motor-car headlight.

The tube was lined inside with black velvet paper. The reflector concentrated the light from the bulb on to any surface placed across the open end of the tube.

A part of the light diffusely reflected from such a surface passed up the side tube arranged at an angle of 30° to the incident light and was received on the photo-electric cell. The output from this cell, which was of the rectifier type, was recorded on the galvanometer. Energy was supplied to the lamp from accumulators housed on the baseboard, the voltage of the supply being controlled by the voltmeter and rheostat. For the calibration of the instrument a diffusing plate of known reflection factor was placed over the mouth of the tube, and the galvanometer reading recorded. The tube was then placed against the article of clothing, and the galvanometer reading again noted.

The apparatus was tested for linearity and for colour response. Up to a reflection factor exceeding 80 per cent. the output from the cell was directly proportional to the reflection factor On coloured surfaces the reading of the instrument agreed quite closely with direct visual measurements except where the colours were situated near the red end of the spectrum and were fairly pure. Since light reflected from clothing seldom showed any approach to purity, this defect was of no importance.

Discussion of Results.

As any part of a pedestrian may present at any instant a contrast with some part of the background, it is necessary to measure the reflection factors of coats and trousers in the case of men, and coats and stockings in the case of women. The original measurements were made during the winter months.

A typical set of results using Method III. is shown

in Fig. 2 for a group of 100 men and 100 women selected at random. The figure illustrates the somewhat surprisingly low reflection factors of garments worn during the winter. Measurements made on other groups of people and by Methods I. and II. all showed the same general distribution.

During the summer, women, in particular, wear clothing of lighter colour, and, in consequence, it appeared desirable to make a further set of observations during the summer. A typical set of results are shown in Fig. 3, with part of Fig. 2 inserted for comparison. A similar set of observations on men's clothing for summer conditions has not been made as it was felt that although there would be some shift towards higher values, the distribution would not be greatly changed.

Combination of Results for Calculation of Revealing Power.

The results as plotted in Figs. 2 and 3 are not

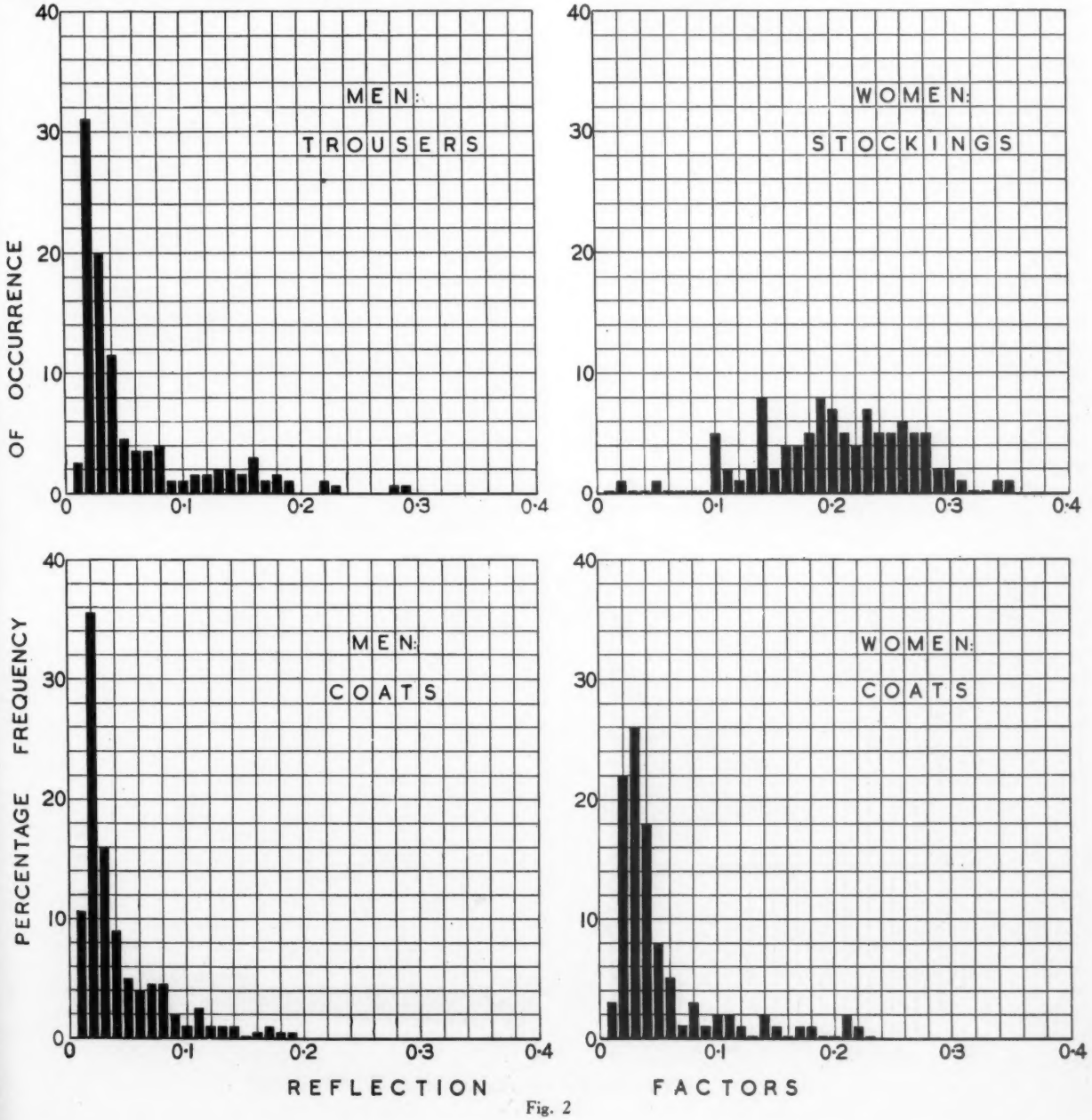

Fig. 2

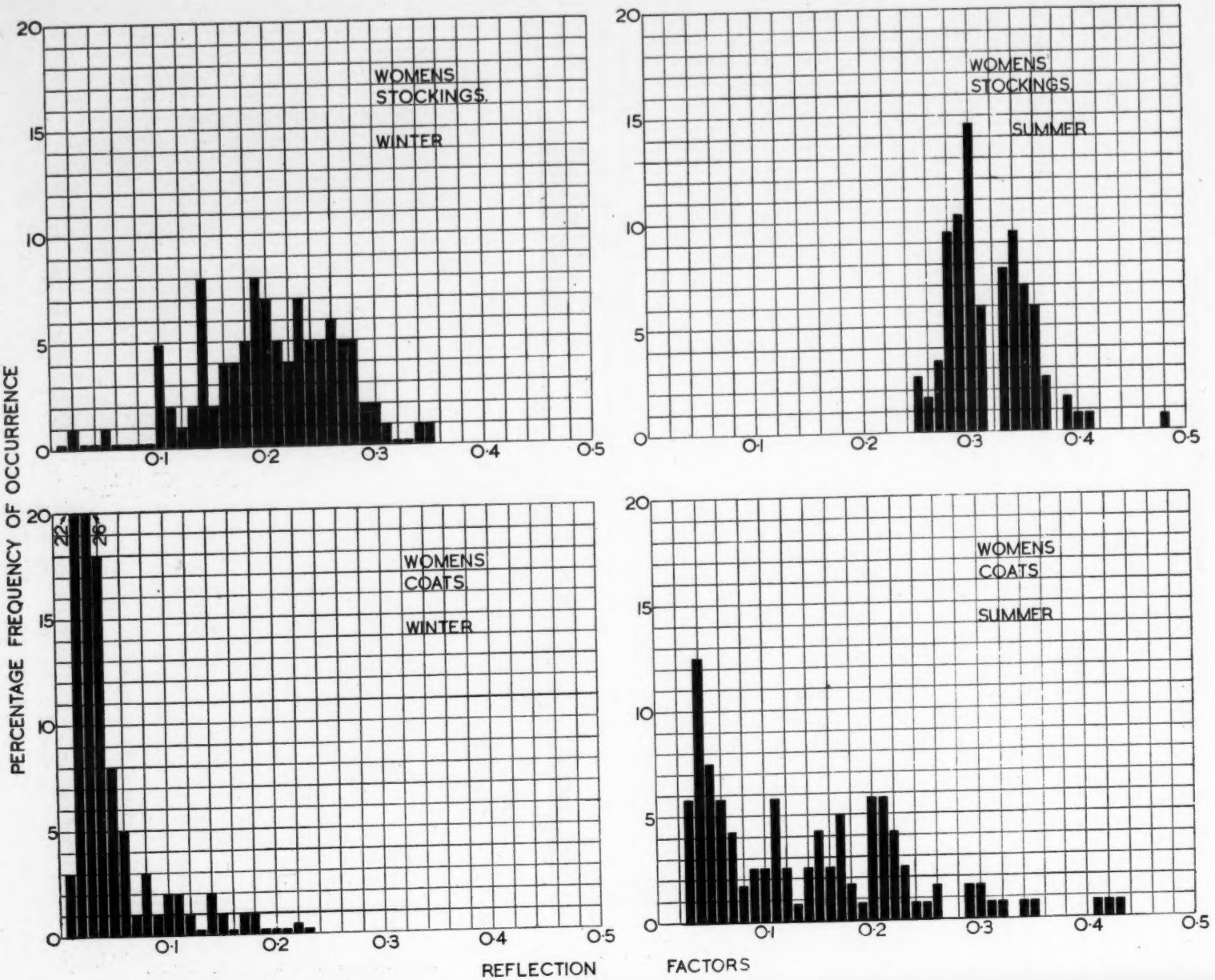

Fig. 3

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in a suitable form for use in the calculation of revealing power. Any method of compounding the results for the above purpose must in the nature of things be somewhat arbitrary and open to criticism. The following is suggested as a reasonable method.

In the first instance, the charts of Figs. 2 and 3 are redrawn in such a way that the percentage of persons wearing clothing having reflection factors *not exceeding* a given value can be read off directly. This has been done in Fig. 4, which includes all the observations made by the three methods. As an example of the use of this curve it will be seen that 65 per cent. of men's coats have reflection factors not exceeding 4 per cent.

The curves given in Fig. 4 have not all equal significance since, generally speaking, trousers and stockings will form a much smaller proportion of the silhouetted figure than coats. Some weighting is, therefore, essential before the facts shown on Fig. 4 can be compounded into two curves both representative of men and women under winter and summer conditions. For the purpose of this work the relative areas of coats and stockings or trousers have been taken as being in the ratio of 3 : 1. Weighting the curves in Fig. 4 in these ratios and treating summer and winter conditions separately, a single curve for men and another for women for each season is obtained. In order to obtain a single curve for each season which will represent the frequency of occurrence of any reflection factor not exceeding a given figure, these curves must be weighted in accordance with the relative proportion of men to women pedestrians. These relative proportions will vary considerably in accordance with local conditions. Observations made in and around London over hourly periods between 6 p.m. and 2 a.m. indicated that there are about 40 per cent. more men than women pedestrians. The final curves A and B shown in Fig. 5 were obtained by applying a weighting of 1.4 to 1 men to women to the curves described above.

In Fig. 5 is also shown a curve marked C, which is an attempt to combine the curves for summer and winter conditions into a single curve representative of the whole year. This final curve C was obtained by weighting the curves A and B in proportion to the hours between lighting-up time and midnight over the periods to which the results refer, i.e., October to March and April to September.

The three curves of Fig. 5, therefore, represent, subject to the conditions and assumptions made above, the probability of the occurrence of a reflection factor not exceeding some given value.

Work of a similar character has been carried out in both Holland and America. The former work quoted by Van der Werfhorst (1) shows frequency

(1) G. B. Van der Werfhorst, "Technical Considerations in the Lighting of Country Roads." Philips Tech. Rev., 2, 239, 1937.

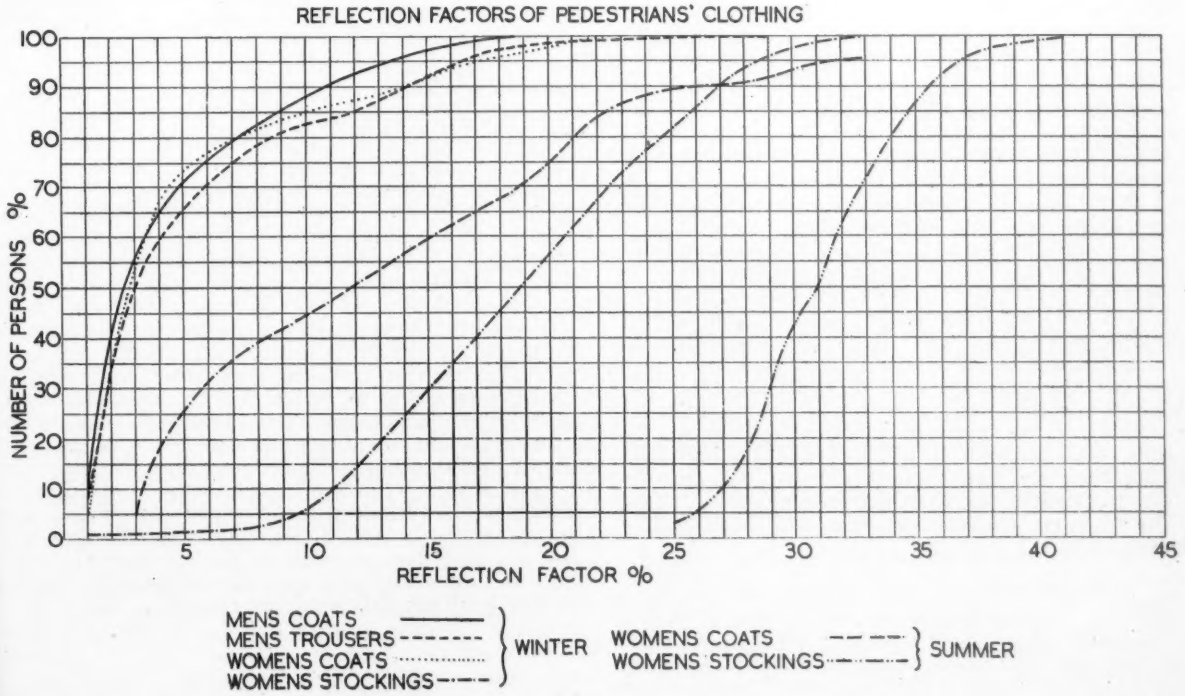

Fig. 4

of occurrence curves for overcoats and suits with maxima at 0.8 per cent. and 1.6 per cent. respectively, which is substantially in agreement with the results given in this paper.

The American work referred to was that by P. Moon and M. S. Cettei (2), who were concerned more particularly with the spectral distribution of reflection factors of representative clothing samples illuminated by incandescent, mercury and sodium discharge sources.

(2) Jour. Optical Society of America. 28, 277, 1938.

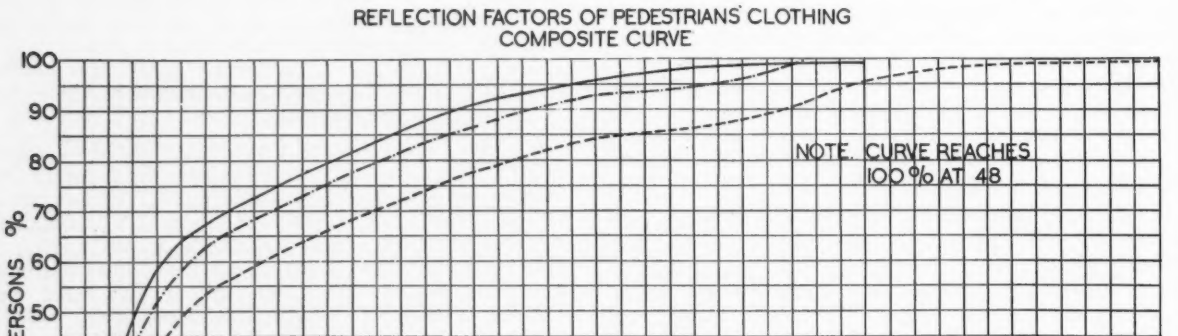

Fig. 5.

B. SUMMER CURVE ----------
C. COMBINED WINTER & SUMMER —·—·—
A. WINTER CURVE ————————

DISCUSSION

The CHAIRMAN (Dr. S. English), remarking on the comment by Mr. Waldram in presenting his paper that they had been attempting to "fathom the unfathomable," said that whether they had succeeded or not it would be agreed that they had got into some fairly deep water. At the same time, he felt that those who had listened to the papers would feel that they had been led to appreciate something about the revealing power of a street lighting installation, and for the authors to have done that was no mean achievement. The amount of experimental work which the papers represented was simply colossal. On behalf of the meeting he expressed the sincere thanks of all present for what the authors had done and for the very pleasing and instructive manner in which the papers had been presented.

The vote of thanks was accorded with hearty acclamation.

Dr. C. C. PATERSON, after referring to the lucid manner in which the authors had presented such a complicated subject, said that all those present must feel that the mists had begun to clear away from some of our methods of thinking about the question of visibility or revealing power. The work which had been done by the authors could only be described as courageous and should lead to the establishment of a standard based on fundamentals which even though at present applied only with approximation, gave a sound basis for the future. To have done that was indeed a very great achievement. The papers had shown that the whole subject aligned itself in a statistical framework, as indeed it should do, because when one came to think of it, the only basis on which it was possible to assess the revealing power in a street must be in terms of the answer to the question, "What are the chances of seeing an object?" That was the basis of the work and the theory on which the authors had proceeded, and the more the question was thought about the more would it be seen that that was the only really correct conception for appraising it. Whilst congratulating the Society on having had these papers presented, Dr. Paterson said that if it had not been for the policy of the Ministry of Transport and the attention which that Ministry had called to the problem this conjoint attack on the subject could hardly have taken place.

Mr. D. G. SANDEMAN, by the aid of a blackboard diagram, contended that if the top portion of the

illumination distribution curve measured upon a vertical plane placed at different points throughout the span were removed visibility would be improved very considerably. That could be done very simply by altering the design of the lighting units. He indicated a possible modification which would result in there being more light below the lamp and plenty of light near the horizontal. The intermediate angles 30° to 75°, having a reduced candle power, there would be an increased contrast of objects viewed throughout the span. In addition, glare would be reduced to a constant value and the road surface would be brighter.

Mr. L. T. MINCHIN said he would like to give one word of caution which he hoped would not be taken as in any way undervaluing the brilliant work which the authors had done. The point was that revealing power had no significance except in conjunction with the particular object which was to be revealed. In the papers, as he understood them, the revealing power was related to a small round object, but, of course, in a street where there were pedestrians, cyclists, and motor cars, all of whom varied in shape and none of whom were circular. Therefore it was important that the dark patches should not be so shaped as to fit the objects which it was most important to distinguish from the background. Unfortunately, however, this was what happened with normal street-lighting. The black patches, where they occurred, were in the middle of the road or along the kerb, and were of about the right shape and size just to obscure a cyclist or pedestrian. Therefore consideration must be given to the shape of the darkest patches. If these patches were small they would not matter, except for the smallest objects. If the objects were broad and fairly short, the usual kind of dark patch would not matter very much but, unfortunately, very few of the objects it was necessary to observe had this shape. Great care should therefore be taken to avoid those dark patches with which so many of them were familiar, viz., long and narrow ones which were just the right shape to hide a pedestrian or cyclist. More important than the actual value of the revealing power was its distribution in the field of view.

Dr. J. W. T. WALSH, remarking that all the work described in the paper had been done with white light, said that a great deal of street lighting was now done with sources of a marked colour. It would be interesting to see to what extent the conclusions of the authors would be affected in the case of such coloured lighting. What was the possible effect of colour on the critical contrast curve in Mr. Dunbar's paper, and did either of the authors think that that curve might be considerably modified by coloured street lighting? The only clue he could get to an answer to that question was the similarity of the curve in Fig. 6 of Mr. Dunbar's paper to the curve with which they were all familiar, viz., the Fechner-fraction curve, which was the threshold counterpart of Mr. Dunbar's curve. As the Fechner-fraction curve was not greatly affected by the colour of the light then Fig. 6 in Mr. Dunbar's paper might not be much affected either. He might be treading on rather dangerous ground, but he would like to hear the author's reaction to this suggestion.

Mr. R. G. HOPKINSON commented on the remark in Mr. Dunbar's paper that the critical contrast in an isolated dark patch is greater than in a uniform field of the same low brightness because the surrounding bright field acts as a secondary glare source, and suggested that this increase in critical contrast might be due to two effects. One of these is the existence of a veiling brightness due to the glare effect of the bright surround, and the other is due to the fact that the eye, when viewing the uniform field of low brightness, is in a low state of adaptation, and can therefore percieve small differences of brightness whilst when viewing the dark patch in the bright surround, the eye is adapted to a general level of brightness many times greater, perhaps not quite ten times as great, but approaching that value, depending, of course, on the relative sizes of the dark patch and the surrounding field. Because of this higher adaptation level the eye is therefore less sensitive to brightness differences in the patch of low brightness. It appeared to him that this change in the general adaptation level may be the chief cause of the increase in the value of the critical contrast, and that the veiling effect of the adjacent bright field is perhaps relatively less important. It would therefore be of interest to know if a practical test had been made to establish that the same critical contrast curve will hold for both uniform and non-uniform backgrounds, or whether the validity of using the same critical contrast curve depends on the assumption that the secondary glare effect of neighbouring bright patches is the major cause of the increase in critical contrast for a patchy road.

Mr. E. S. PERRIN said that as a member of the Ministry of Transport he wished to express the thanks of the Ministry to the members of the Technical Panel, and particularly to the three authors that evening, for the work that had been done to assist the Ministry. It was quite true that the Ministry was responsible for the funds for putting up the installation, but it was not responsible for any funds for paying the members of the Panel, nor the three authors. These gentlemen did all this work willingly at their own expense, and went out at night in wet and very unpleasant weather very often, and, therefore he wished to thank them sincerely for what they had done. So far as the papers were concerned he had felt a little guilty in listening to Mr. Waldram, because he was partly responsible for asking Mr. Waldram to solve an unsolvable problem. He was able to ask that to be done because he was not an expert on the subject, and, that being so, he was, perhaps, allowed to be foolish. Nevertheless, the results had shown how useful it was sometimes to have a foolish person on a committee to ask a silly question, and it seemed to him that before long Mr. Waldram would be able to give a solution which would be very useful in the future. The trouble all

the way through had been that nobody had hitherto known how to appraise a lighting installation. The authors, however, had shown one way of approaching the problem.

Mr. J. S. Dow referred first to the method adopted by Messrs. Waldram and Dunbar of defining contrast as a "difference in brightness." There did not appear to be one authentic scientific definition of the term "contrast." In other researches it had been used to denote "ratio of brightness," and in yet other cases to express a more complicated factor in which both the difference and the ratio of brightness entered.

He noticed Mr. Dunbar's estimate of an effect of glare, amounting in one case to 28 per cent. This was a recognition of the fact that glare did, in fact, prejudice the effect of street lighting. At the same time he rather questioned the conception that in the case of an unduly glaring installation it might be possible to counteract the effect of glare by achieving a certain increase in the contrast of objects observed. This might be effected in some degree when one was concerned simply with a silhouette effect. But there were some disabilities of glare that could hardly be compensated by giving more light on the roadway. It might even happen—as one sometimes observed in bright sunlight—that light reflected from the roadway itself gave rise to glare and created excessive contrast.

Continuing, Mr. Dow said the question of the effect of colour mentioned by Dr. Walsh had always been a pet subject of his. He believed that the subject was more complicated than was usually imagined. It was not a question only of the reflecting power of the road surface. There was also the well-known Purkinje effect, the chief manifestation of which was that areas illuminated by light from the green and blue end of the spectrum tended to appear brighter at weak illumination than photometric measurements under normal conditions would suggest. In this connection one had to consider the effect of the area of the retina on which the image was received. If the eye viewed a large area of roadway, subtending a big angle at the eye as compared with the small surfaces dealt with in the laboratory, the difference might be very considerable. There was also the question of the effect of chromatic aberration of the eye. The eyes of many people were unable to focus light from the blue end of the spectrum, at some little distance. That had one effect, that when one looked at a road lighted by mercury lamps, the whole area seemed to be "full of light" because of the spread of the blue radiation, which produced a species of luminous haze, having the effect of diminishing the contrast.

Finally, Mr. Dow mentioned the view held by some that there was yet another effect, due to the fact that at very low illuminations sensation developed more rapidly for light of some colours than in the case of others; that might tend either to accentuate or diminish contrast effects. In general, these factors were not of serious moment at high levels of illumination. But where one had to deal with large areas only very weakly illuminated they might well have a material influence on results.

Mr. J. PRESTON pointed out that one of the tests applied by the authors related to a stationary object, but he had been wondering how many stationary objects would be encountered in a street. The great majority of objects encountered in driving were not stationary. Any such object, therefore, would probably remain in the area of invisibility for only a very short time, the chances of an accident arising from such invisibility being therefore generally less than in the case of a stationary object. He was consequently interested in knowing how far the factor of movement came into consideration in the appraisement of merit of a street lighting installation as distinct from the method of appraisement mentioned in the papers. Nothing had been said on that point.

Commenting on the view that the silhouette method of vision was an important one from the street lighting point of view, he suggested the possibility of using systems of street lighting in which all the lights were not above, say, 4 ft. from the ground, thus permitting of a high road brightness, with considerable diversity certainly, but showing every object as a black outline with no brightness whatever. He had seen such systems, but he believed there was a certain psychological dislike for them. He asked for the authors' opinions as to the reasons why this method was not tried out more often or whether it was already obsolete.

Mr. A. CUNNINGTON, commenting on the fact, as brought out by Mr. Waldram, that very few conditions in street lighting were really under the control of the lighting engineer, said he was hoping the time would soon come when, at all events, the important matter of the reflecting surface of the road would be at least partly under his control. Lighting engineers should be more fully consulted by road engineers in this matter, and he recalled that at a "Safety First" conference of road engineers some little time ago a strong preference was expressed for a concrete surface where cost would permit. The road engineer was therefore generally in accord with the lighting engineer.

He referred to the danger of emphasising any one particular feature of street lighting so as to give the impression that this was the sole factor to be taken into account. He did not suggest the authors were guilty of this mistake, but it was possible to attach too much importance to one feature. For instance, in listening to the paper, he found himself being convinced against his own views that an installation with some glare might be better than an installation without glare. He, personally, was surprised that more use was not made of the cut-off in street lighting installations. He felt there had been too much neglect of the cut-off design, possibly because of the tendency to make the best use of existing circumstances and existing types of lamps available. Could not some effort be made to indicate more or less the ideal form of light distribution without regard to any particular lamp, height, or spacing? It would then

be the task of the lighting engineer to get as near this ideal as possible without tying himself too closely to existing ideas. This would possibly mean the multiplication of light sources, or it might even be found that a lower illumination would suffice. His main point was that too much stress should not be laid on particular aspects of the street lighting problem in such a way as to stereotype existing systems.

Dr. S. ENGLISH (*communicated*): As already indicated, I have the greatest admiration for the enormous amount of work that has been put into the preparation of the three papers we listened to on various aspects of the street lighting problem. The results put forward are obviously above criticism, but some of the arguments used in Mr. Waldram's presentation may, I think, be questioned.

For example, simply because we cannot define visibility in precise terms, Mr. Waldram thinks we should not try to estimate it by empirical experiments but rather that we should determine those characteristics of street lighting installations which lend themselves to precise definition and measurement. Such measurements are admittedly useful in helping us to understand the mechanism of vision on lighted roadways, but they do not give us a measure of visibility unless some empiricism is used in their interpretation, and in my opinion empiricism at this stage is quite as unreliable as that involved in making direct estimates of visibility for comparison purposes.

Let me illustrate my point by assuming Mr. Waldram wants to buy an easy chair. Since there is no precise definition of comfort, he will ask the shopkeeper how many springs are used in the chair, their strength, and placing, etc., and from such information he will calculate the "springiness" of the upholstery. But these figures by themselves will not indicate that the chair is properly proportioned and shaped to fit an ordinary person. All these need combining in an empirical manner in order to get an idea of "comfortableness," but if Mr. Waldram *sat* in the chair he would at once automatically combine all these and other factors giving each one its proper importance without actually measuring any one of them. With a little practice he would be able to sit in half a dozen chairs and then without any hesitation place them in order of "comfortableness." Similarly, I suggest that in practice we can estimate the visibility in streets, for the purpose of comparing one installation with another, by using a direct method, empirical, it is true, but, nevertheless, sound, so long as it is only used for comparison purposes.

I gave details of such a method in a paper to this Society in 1936, and, in collaboration with Mr. Stroud, gave some results of applying this method on a London street to the Association of Public Lighting Engineers in 1937. The validity of this method is strikingly confirmed by a comparison of the results obtained by it and the indications contained in Mr. Waldram's papers.

To consider one case only, Mr. Waldram shows in Fig. 7 a photograph of an installation comprising staggered units and giving a test point illumination of 0.08 ft.c. Figures marked on the photograph indicate that the "revealing power" down the middle of the road varies from 90 per cent. to 99 per cent., while down the off side it falls to less than 75 per cent., and down the near side to less than 50 per cent.

Our direct measurements of visibility on a road with a staggered installation of dome refractors giving an average test point illumination of 0.077 ft.c. gave, with the light sources shielded to obviate glare, 94 per cent. visibility down the middle of the road, 54 per cent. down the off side, and 34 per cent. down the near side. Bearing in mind the marked difference in road surface and contour, the results show remarkable agreement, and taken in conjunction with eleven other complete sets of data that we published, we may look upon Mr. Waldram's indirect results as a welcome confirmation of the results which we obtained by direct measurements.

Mr. F. C. SMITH, replying to the discussion, remarked that there was little that called for comment by him. He expressed appreciation of what Mr. Perrin had said, and said that although it was true that some of the work was done under very wet and unpleasant conditions, all the investigators had got a good deal of pleasure out of the investigation.

Continuing, he said he was tempted to talk about the question of coloured light and its effect on visibility, but he would prefer to do this on another occasion. At the same time it might be proper for him to state that in his opinion all the facts in regard to coloured light and its relationship to visibility were not known, and a great deal of work remained to be done before an authoritative statement could be made in this respect.

In regard to Mr. Cunnington's remarks, Mr. Smith stated that he had a great deal of respect for the view Mr. Cunnington had expressed, and felt it was possible that the method, if applied to cut-off installations, might lead to a wrong evaluation. He felt he would like to look at this matter again basically. Frankly, in his view, many of the cut-off installations were very good, and it should be clear that all three authors were not agreed on every aspect of street lighting. They had their differences, and he could easily criticise some things that his colleagues had said that evening, but they could do the same in regard to the remarks made by himself. Therefore, they had each presented their part of the work and left the matter there.

Mr. C. DUNBAR, in his reply to the discussion, expressed his thanks to Dr. Paterson and Mr. Perrin for their appreciation of the work, and for their recognition of the fact that the results had to be obtained at night under conditions which were often far from pleasant. He said Dr. Walsh was correct in his remark that this work had been confined to the case of "black and white" vision. It was also true that the curve in Fig. 6 of his paper was very similar to the Fechner fraction curve obtained in laboratory threshold experiments. In fact, if all the ordinates of the Fechner fraction curve for an object of the same effective angular size were multiplied

by a constant factor, the curve obtained would be a close approximation to that in Fig. 6.

Mr. Dunbar agreed that with the increasing use of mercury and sodium gaseous discharge tubes as street lighting units, the question of the effect of colour on the critical contrast curve became very important. He had been carrying out experiments himself on visual efficiency and colour in street lighting installations, and other work had been done in America by Channon and Reid. In the case of objects and backgrounds which were non-selective in their reflection properties, this work indicated that if the colour of the light illuminating an object and its background was changed without the photometric brightnesses of the object and background being altered, then the probability of the object being detected by an observer would be independent of the colour of the light. (By photometric brightness was meant the brightness value based on the international visibility curve.) In other words, it was to be inferred that the critical contrast curve would be independent of the spectral distribution of the street lighting units.

With regard to Mr. Dow's comments on the possible effects of the colour of the light on object visibility Mr. Dunbar felt that while claims based on chromatic aberration and the Purkinje effect had been made on behalf of particular spectral distributions, the experimental evidence in favour of these claims was unconvincing, and the work mentioned previously indicated that these factors were not so important in street lighting as some imagined.

Mr. Hopkinson had raised the point as to the exact mechanism which caused an increase in the critical contrast for an object in a dark patch if the patch were surrounded by a large area of higher brightness. Mr. Dunbar said that he had referred to this in his paper as a disability glare effect. Whether this increase in the critical contrast was in fact due to a kind of veiling brightness or was more logically explained by a change in adaptation level (i.e., by interaction across the retina) or by a combination of the two effects was a rather difficult question. He would like to point out, however, that whatever the exact mechanism might be, the important thing was that both outdoor and laboratory work had shown that integrating up the effect of the surrounding higher brightness according to the "equivalent background" formula gave approximately the same increase in necessary contrast as that determined experimentally. There seemed to be no objection, therefore, to the method which had been used in the paper for evaluating the effect on the critical contrast of a non-uniform brightness distribution.

Mr. Preston had commented on the fact that the tests had been restricted to the case of stationary objects. Mr. Dunbar admitted that the critical contrast curve applied only to such cases, and therefore did not fully take into account all the effects of motion. If an object was moving the critical contrast would be smaller than for a stationary object, and the true revealing power of an installation would be somewhat higher than that given by the critical contrast curve. It was pointed out in the paper, however, that for the problems to which this method of assessing the revealing power of an installation was to be applied, the limitations imposed on the object would not be likely to mislead the investigator. The question of moving objects did mean, however, that care should be exercised in considering the revealing power contours, and undue weight should not be attributed to small areas of low revealing power out of which an object could quickly move.

With regard to Dr. English's communication, Mr. Dunbar feels that too much significance should not be attached to the similarity of the figures obtained in Dr. English's work and those obtained in the present investigation. The two investigations do not measure the same thing. Although Dr. English viewed the road surface through his test disc, he has, in effect, used an object of fixed reflection factor (12 per cent.) and a stationary observer, and has determined the average probability of the object being detected if it occurs, for example, near the centre of the road. The object is not always seen against the same region of the background. The investigation described in these papers is concerned with the percentage of all possible objects which will be revealed to the driver of a car by any region of the background. These practical objects may have reflection factors which vary over a wide range.

It is, at first sight, rather surprising that the visibility figures obtained by Dr. English should be so low, since for an object of a specific size the threshold contrast for a stationary observer would be much smaller than the critical contrast for the driver of a car. The explanation seems to be that Dr. English has used, in effect, an object of very small angular size (approximately 0.07 deg.)—much smaller than objects in which the road user is generally interested—thereby rather artificially increasing the threshold contrast. He has also used an object reflection factor which is well above the average value encountered in the street. If he had used scale objects and a reflection factor nearer the average practical value, a similarity between the results of the two investigations would hardly have been obtained. The use of an object with a fixed reflection factor of 12 per cent. is a rather dangerous procedure in assessing the visibility of objects in a street, since although this object may be invisible against a particular region of the background, objects of other reflection factors may be visible since approximately 80 per cent. of practical objects have reflection factors less than 12 per cent., it is not difficult to imagine circumstances in which Dr. English's method would give equal visibilities to regions which actually revealed practical objects to very different degrees.

In the circumstances Mr. Dunbar hardly feels that the results of the two investigations can be taken as confirming one another.

Mr. J. M. WALDRAM, making the final reply, added his thanks to those of the other two authors to Dr. Paterson and Mr. Perrin for their appreciation. He referred to the part played in the work by the Chairman and the Secretary of the Experimental Panel, Mr. A. E. N. Taylor and Dr. Gillbe, who had taken

part in all the experimental work and who had most ably directed all their discussions. All three authors owed a great deal to their enthusiasm and example.

Mr. Sandeman had suggested a modification to the polar distribution of the lantern in order to keep the illumination of objects as low as possible. Mr. Waldram referred to a system upon which Dr. English and he had been working independently in which something of the kind had been done. While this was possible in roads used only for one-way traffic, in normal roads the effect of so modifying the light distribution was to modify the brightness distribution also on the off-side of the road, and the appearance of the installation would be unsatisfactory. Unfortunately, the part of the distribution which it was necessary to modify to decrease object brightness was very sensitive; it was necessary to find the best compromise among several conflicting factors.

Mr. Minchin had raised an important point which could be coupled to one raised by Mr. Preston. It was most important to avoid the formation of dark regions of such a size and shape that an object could be lost in them; and particularly so if the object could remain against a dark region until it was approached too close to be avoided. This was one of the reasons for expressing revealing power in the form of contours, so that the shape and position of dark areas could be gauged.

He was particularly interested in Mr. Dow's remarks on the proper expression of "contrast." On this matter Mr. Waldram differed from Mr. Dunbar, for he contended that contrast was a sensation, and could not, therefore, be readily measured or expressed in numbers. In considering an object having a different brightness from the background against which it was seen, it was legitimate to refer to the ratio of their brightness, or the absolute difference, or the relative difference between them; but none of these functions expressed numerically the sensation of contrast which the observer received. To be complete, the adaptation level to which he was adapted should also be stated.

He hoped, therefore, that the term "contrast" would become restricted to the sensation of contrast, and the other commonly used functions referred to as "brightness difference," "relative brightness difference," or "brightness ratio" as the case might be. Some very erroneous conclusions had been drawn from the numbers expressing one of these functions as the result of misconceptions regarding their meaning.

Mr. Preston had advocated the use of low mounting. This system had often been advocated and sometimes tried, but was never successful for many reasons; one of which was the impossibility of providing a bright background from low mounted lanterns, since the size of the bright area produced by each lantern was very restricted.

Mr. Cunnington hoped for further co-operation between the road engineer and the lighting engineer, and more consistent surfaces for the lighting engineer to light. Such co operation was beginning, both in this country and in America, and was greatly welcomed. There were several surfaces commonly used which were capable of giving good results; the difficulties were met with mostly by the extreme surfaces. Between, for example, some asphalt and some concrete surfaces there was less difference than might be supposed, and it would be difficult to make a case for standardising one surface.

On the other hand, the provision of a standardised surface would not enable much more stable figures of revealing power to be obtained, on account of differences in reflection properties due to wear, weather and soiling of the surface, which alone would still be so great as to preclude the use of revealing power measurements for an acceptance test or a maintenance test.

Mr. Cunnington had referred to the comparatively small use of the cut-off system. There were good reasons, which were quite well understood, why a cut-off system was difficult to apply in practice in many situations, apart from the question of cost; it was a system capable of very good results, but its field of application was restricted. There could be no such thing as an ideal light distribution considered apart from height and spacing and other installation characteristics, for they were all inter-related; a distribution ideal for one type of installation might be a failure if used in another. Mr. Waldram did not expect to see any very radical change in the method of lighting streets, for engineers had found by trial and error systems of lighting which were sound and practicable and upon which no very considerable improvement seemed likely at present.

Mr. J. M. WALDRAM has sent the following reply to Dr. English's written communication:—

Dr. English challenges the statement in my paper that unless a quantity or property can be precisely defined it cannot be measured or properly expressed in numbers. Surely Dr. English is tilting at an axiom. The very example which he has quoted proves his contention to be misconceived. To *measure* a quantity involves expressing it in numbers on some proper scale, the system of numbers and the methods of measurement being so devised that the numbers are in a known relation to the effect to be measured. Before any proper system of measurement can be devised, it is obviously necessary to know precisely what is the quantity which it is desired to measure, and how it is affected by extraneous factors, and so on. Only those quantities which can be so defined can be measured, and there are really comparatively few of them. One measures the *weight* of a pound of tea, for that is one property which can be defined. But the judging of the real excellence of the tea has to be done by a tea-taster, for it is not a scalar or definable quantity which can be expressed in numbers. Neither is "visibility."

In Dr. English's illustration of the easy chair he rightly points out that with experience an observer can place several chairs in an order of merit. But that is not measurement. Such experiments have been done in street lighting, for example, by Stiles and Dunbar, in 1931. and by Jolley, Watson and myself, in 1927. but Dr. English's own experiments were not on that basis. He did not place installations in an order of merit on the judgment of experienced

observers but made certain tests to produce numbers which were called "visibility," which is a very different thing. His test consisted in viewing an arbitrary test object in arbitrary positions, and deciding by an arbitrary criterion whether it could be seen; and in almost all respects the conditions of his experiment differed seriously from those under which a driver views a street and the objects upon it. Experiments of that kind are, of course, legitimate if they are used only to find when such an object is visible under those conditions; but to call the numbers "visibility" is pure assumption. It is not possible to step from either his numbers or mine to "visibility."

There is no fundamental objection to an arbitrary test as such: my own method includes several arbitrary factors, and even respectable fundamental units are, in the end, arbitrarily defined. But an arbitrary test, to be valid, must be designed with due regard to the quantity tested. It is not sufficient to hit upon some criterion and arbitrarily adopt it as the measure of a quantity without ascertaining whether it depends uniquely upon that quantity. The conditions of Dr. English's test are, in my opinion, too artificial and too liable to be unduly influenced by extraneous factors for the results to be reliable; and in view of the different meaning which attaches to his numbers, and the difference between the installations tested, I am afraid that the coincidence of the numbers which he quotes is accidental.

Applications for Membership.

Elections Pending.

At the general meeting of the Society held on December 13, the names of the following applicants for membership were presented for the first time:—

SUSTAINING MEMBERS:—

Franklin Lamp Manufacturing Co., Ltd. ..... Vereker Buildings, Rathbone Place, LONDON, W.1.
Representative ..... Mr. Alan L. Smith.

Metropolitan - Vickers Electrical Co., Ltd. ..... No. 1, Kingsway, LONDON, W.C.2.
Representative ..... Mr. N. V. Everton.

CORPORATE MEMBERS:—

Briden, H. ..... J. Ismay and Sons, Ltd., Roden Street Works, Ilford, ESSEX.
Cartlidge, R. ..... 25, Motspur Park, New Malden, SURREY.
Chesterton, A. T. ..... British Thomson - Houston Company, Ltd., 42, King Street West, MANCHESTER.
Dunbar, C. ..... Photometry Division, National Physical Laboratory, Teddington, MIDDLESEX.
Dixon, M. L. ..... The General Electric Company, Ltd., Magnet House, Kingsway, LONDON, W.C.2.
Embers, C. W. ..... 47, Norbury Road, Thornton Heath, SURREY.
Einon, D. ..... J. Ismay and Sons, Ltd., Roden Street Works, Ilford, ESSEX.
Farthing, J. H. ..... The General Electric Company, Ltd., Victoria Bridge, MANCHESTER.
Garsden, F. W. ..... Lloyds House, Albert Square, MANCHESTER.
Hanson, G. R. ..... High Winds, Hawkstone Avenue, Guiseley, near LEEDS.
Harborne, S. ..... J. Ismay and Sons, Ltd., Roden Street Works, Ilford, ESSEX.
Heywood, S. ..... The Liverpool Gas Company, Duke Street, LIVERPOOL.
Hogan, J. R. ..... 72, Park Road, New Barnet, HERTS.
Holmes, Miss E. M. ..... 17 Wilmot Road, LONDON, N.17.
Marx, E. A. ..... 54, Wellington Street, LEEDS. 1.
Mansell, G. ..... J. Ismay and Sons, Ltd., Roden Street Works, Ilford, ESSEX.
Seville, R. O. ..... Electricity Department, Old Town Hall, WAKEFIELD.
Stiles, Dr. W. S. ..... National Physical Laboratory, Teddington, MIDDX.
Ryall, L. A. V. ..... Colwyn, Norton Way, N. Letchworth, HERTS.

COUNTRY MEMBERS:—

Baird, H. ..... Glencoe, Richmond Hill Road, Gatley, CHESHIRE.
Fryer, W. H. ..... 6, Merrion Road, Ballsbridge, DUBLIN.
Franks, H. B. S. ..... 1, Westcott Street, Hull, YORKS.
Hall, D. G. ..... 26, Southcoates Avenue, Holderness Road, Hull, YORKS.
Hare, L. A. ..... 14, Portland Street, MANCHESTER.
Harrison, W. J. ..... Grylands, Maney Hill Road, Sutton Coldfield, WARWICKSHIRE.
Robinson, F. ..... 36, Birch Avenue, Cleveleys, Nr. BLACKPOOL.
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Elections Completed.

At this meeting the names of those announced on November 8, which were published in the issue of "Transactions" (Vol. III., No. 11, p. 164, November, 1938), were read again, and these applicants were formally declared members of the Society.

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